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(Cleveland, OH, 10/16-18/84)

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16. ABSTRACT The proceedings document presentations at the Symposium on Iron and Steel Pollution Abatement Technology for 1984, the sixth in a series, held in Cleveland on October 16-18, 1984. It provided a forum for the exchange of information on technological problems related to multimedia pollution control in the iron and steel industry. American and international representatives from industry, academia, the research community, public interest organizations, and federal and state governments participated. Session 1 dealt with water pollution abatement, Session 2 with air pollution abatement, and Session 3 with solid waste/multimedia pollution abatement.

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ABSTRACT

This report documents presentations at the Symposium on Iron and Steel Pollution Abatement Technology, Cleveland, CH, October 16-18, 1984. The symposium provided a forum for the exchange of information on technology problems relating to water, air, solid waste, and multimedia pollution abatement in the iron and steel industry.

The traditional opening session was eliminated, providing maximum opportunity for the exchange of technical information. Session 1 consisted of eight papers on water pollution abatement. Session 2 consisted of 10 papers on air pollution abatement. Session 3 consisted of seven papers on solid waste/multimedia pollution abatement. The withdrawal of one Session 3 paper (for which an abstract is provided) was counterbalanced by the inclusion of a paper on quenching blast furnace slag with contaminated water.

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STATEMENT OF SYMPOSIUM OBJECTIVES

John S. Ruppersberger
Industrial Environmental Research Laboratory*
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Research Triangle Park, NC

Welcome to the Iron and Steel Pollution Abatement Symposium.

This is the sixth of a series of annual meetings directed towards the exchange of technical information between persons concerned with the environmental aspects of the iron and steel industry. This is our first Cleveland meeting, and we especially want those of you joining us for the first time to feel welcome and to encourage your full participation.

The papers were selected, from abstracts received from the call for papers, by a Program Committee consisting of all persons serving in chairmen positions, representing the cosponsoring organizations: EPA, AISI, and APCA. While serving with this year's Program Committee, it became clear that technically oriented persons from all three cosponsoring organizations share the objective of the Symposium to provide a neutral forum for the presentation and discussion of papers that enhance our understanding of environmental problems and their solutions. I welcome you here and hope you benefit from and enjoy this symposium.

(*)Now, Air and Energy Engineering Research Laboratory.

SESSION 1

WATER POLLUTION ABATEMENT

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NONEVAPORATIVE COOLING OF RECYCLED GAS-PROCESSING WATER FROM A BLAST FURNACE

By W. H. Baum and S. B. Schlosberg
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ABSTRACT

This investigation evaluated nonevaporative (indirect) cooling for minimizing the blowdown of water from blast-furnace-gas cleaning, preferably, to an amount that could be internally consumed.

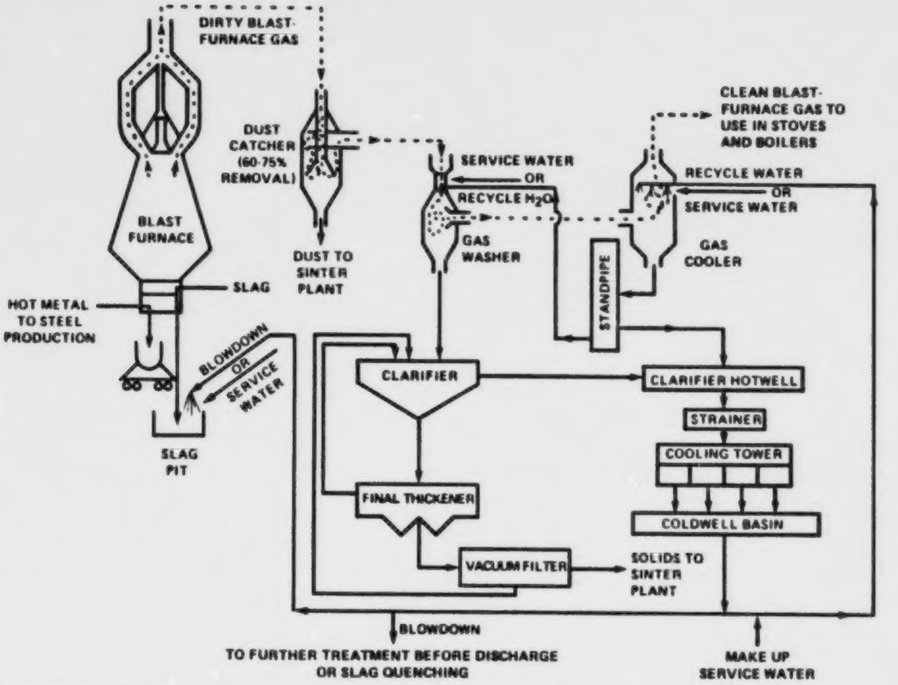
We have demonstrated that a modification of Troy and Crosbie's (1977) concept of nonevaporative cooling effectively limited blowdown not removed with filtered sludge (net blowdown) to an amount that can be evaporated when quenching so-called "air cooled" slag. The pH of the recycled waters was allowed to reach ambient steady-state rather than adding hydrochloric acid as recommended by Troy and Crosbie. Total blowdown averaged about 13 gallons per ton of hot metal (gal/THM) when a furnace burden containing both revert sinter and pellets was used, but increased by about 4 gal/THM when additional pellets replaced sinter.

Operation without acid made use of conserved bicarbonate alkalinity to soften the water during clarification which minimized deposition of calcium salts in other parts of the recycle system. Calcium carbonate scale was not a problem when operating under optimum conditions. Manageable quantities of zinc carbonate and calcium fluoride deposited in the heat-exchanger during optimum operation and were readily removed by mechanical (hydro-jet) cleaning.

Long-term operation of the nonevaporative system demonstrated that the process met design objectives.

INTRODUCTION

Blast furnaces produce significant volumes of low-Btu top gas that are useful as fuel when the entrained dust is removed and the moisture content is reduced. In a typical processing sequence (Figure 1) the gas passes through a dust catcher, a venturi scrubber, and a gas cooler (1)*. Dust that passes through the dust catcher, as well as gaseous water-soluble constituents, are transferred from the gas into the scrubbing and cooling waters.


DIRTY BLAST-FURNACE GAS
DUST CATCHER (60-75% REMOVAL)
BLAST FURNACE
DUST TO SINTER PLANT
SERVICE WATER OR RECYCLE H2O
GAS WASHER
CLEAN BLAST-FURNACE GAS TO USE IN STOVES AND BOILERS
RECYCLE WATER OR SERVICE WATER
GAS COOLER
STANDPIPE
SLAG
HOT METAL TO STEEL PRODUCTION
BLOWDOWN OR SERVICE WATER
SLAG PIT
CLARIFIER
CLARIFIER HOTWELL
STRAINER
COOLING TOWER
COLDWELL BASIN
FINAL THICKENER
VACUUM FILTER
SOLIDS TO SINTER PLANT
BLOWDOWN
TO FURTHER TREATMENT BEFORE DISCHARGE OR SLAG QUENCHING
MAKE UP SERVICE WATER

GENERALIZED SCHEMATIC DIAGRAM: CONVENTIONAL WASHING AND COOLING OF BLAST-FURNACE GAS AND DISPOSITION OF RECYCLED WATER

Figure 1

To meet Best Practical Control Technology Currently Available (BPT) effluent limitations, recycle systems were installed from which only a fraction of the gas-processing waters (blowdown) was discharged (2). The further reductions in discharge allowances required by Best Available Technology Economically Achievable (BATEA) effluent limitations dictate that blowdown be consumed or treated before discharge to public waterways (3). Because some treatments such as the combined alkaline-chlorination/activated-carbon process (4,5) are very costly, it is desirable to reduce blowdown to a volume that can be internally consumed, such as by evaporation on hot blast-furnace slag.

U. S. Steel (USS) installed a nonevaporative (indirect) cooling system at one of its blast furnaces to evaluate nonevaporative cooling as a means to eliminate the discharge of contaminated waters resulting from the processing of furnace top gas. By this design, blowdown is removed as moisture in filtered sludge separated from the process water, with any additional required blowdown evaporated to extinction during quenching of slag produced in the furnace.

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*See References.

BACKGROUND

During processing of blast-furnace gas, carbon dioxide (CO_2) dissolved in gas-washer water reacts with alkaline dust [e.g., calcium oxide (CaO)] suspended in the gas to dissolve the dust as the soluble calcium bicarbonate [$Ca(HCO_3)_2$] salt:

$$2CO_2 + H_2O + CaO \longrightarrow Ca^{2+} + 2HCO_3^- \qquad (1)$$

In conventional systems, gas-processing water is clarified and then cooled by partial evaporation in an open cooling tower. Loss of CO_2 by air-stripping during cooling increases the carbonate (CO_3^{2-}) concentration in the water

$$2HCO_3^- \longrightarrow H_2O + CO_3^{2-} + CO_2\uparrow \qquad (2)$$

possibly resulting in calcium carbonate ($CaCO_3$) supersaturation and scale formation

$$Ca^{2+} + CO_3^{2-} \longrightarrow \underline{CaCO_3} \qquad (3)$$

in the cooling tower and other process equipment and pipes. Lessening the amount of blowdown from conventionally cooled recycled systems (tightening the system) would be expected to exacerbate scaling tendencies.

The concept of nonevaporatively cooling blast-furnace-gas processing water was developed by J. C. Troy and D. A. Crosbie (6). If indirect cooling through heat exchangers were used in place of direct cooling with air as practiced in conventional open towers, they contended, a blowdown rate of less than 0.1 percent could be maintained without $CaCO_3$ formation. They predicted that CO_2 absorbed from blast-furnace gas [concentration typically about 17 volume percent] would be retained during nonevaporative cooling and shift the carbonate - bicarbonate (HCO_3^-) equilibrium in the recycle water towards formation of the latter ion:

$$CO_3^{2-} + CO_2 + H_2O \rightleftarrows 2\ HCO_3^- \qquad (4)$$

Calcium would be present as soluble $Ca(HCO_3)_2$ instead of precipitating as $CaCO_3$. Addition of hydrochloric acid (HCl) to adjust the operating pH to a range of 5 to 6 was also recommended to further limit CO_3^{2-} ion concentration.

OBJECTIVES OF THE STUDY

Because nonevaporative cooling was an unproven concept, a research program was designed to resolve several uncertainties about the method. Some uncertainty existed concerning the selection of an optimum pH range for recycled process waters in a nonevaporative system. The authors believed that the cost of treatment chemicals could be minimized by operating at autogenous pH values instead of adding acid or adding an alkaline stream, as later mentioned by Crosbie (7). Loss of CO_2 (equation 2) was expected to occur in the flume conveying recycle water to the clarifier and during the retention period in the clarifier. It was anticipated that sufficient CO_2 would be so lost to supersaturate the water with respect to CO_3^{2-} and calcium (Ca^{2+}) ions and to induce precipitation of a sparingly soluble $CaCO_3$ salt in the clarifier (equation 3) instead of in the heat-exchanger tubes.

A second uncertainty involved Troy and Crosbie's estimate that 52 pounds (6.2 gallons) of water per ton of iron produced would be removed in dewatered sludge. Unprocessed blast-furnace gas typically has 8 to 9 mole percent moisture from the burden materials and the air blast. Calculations indicated that at this moisture level the condensate from the cooled gas would exceed 6.2 gallons per ton of hot metal (gal/THM).

A third uncertainty was the need for corrosion resistant materials to construct the heat exchangers. Troy and Crosbie expected the recirculating waters to have a low dissolved oxygen content and corrosion to be minimal.

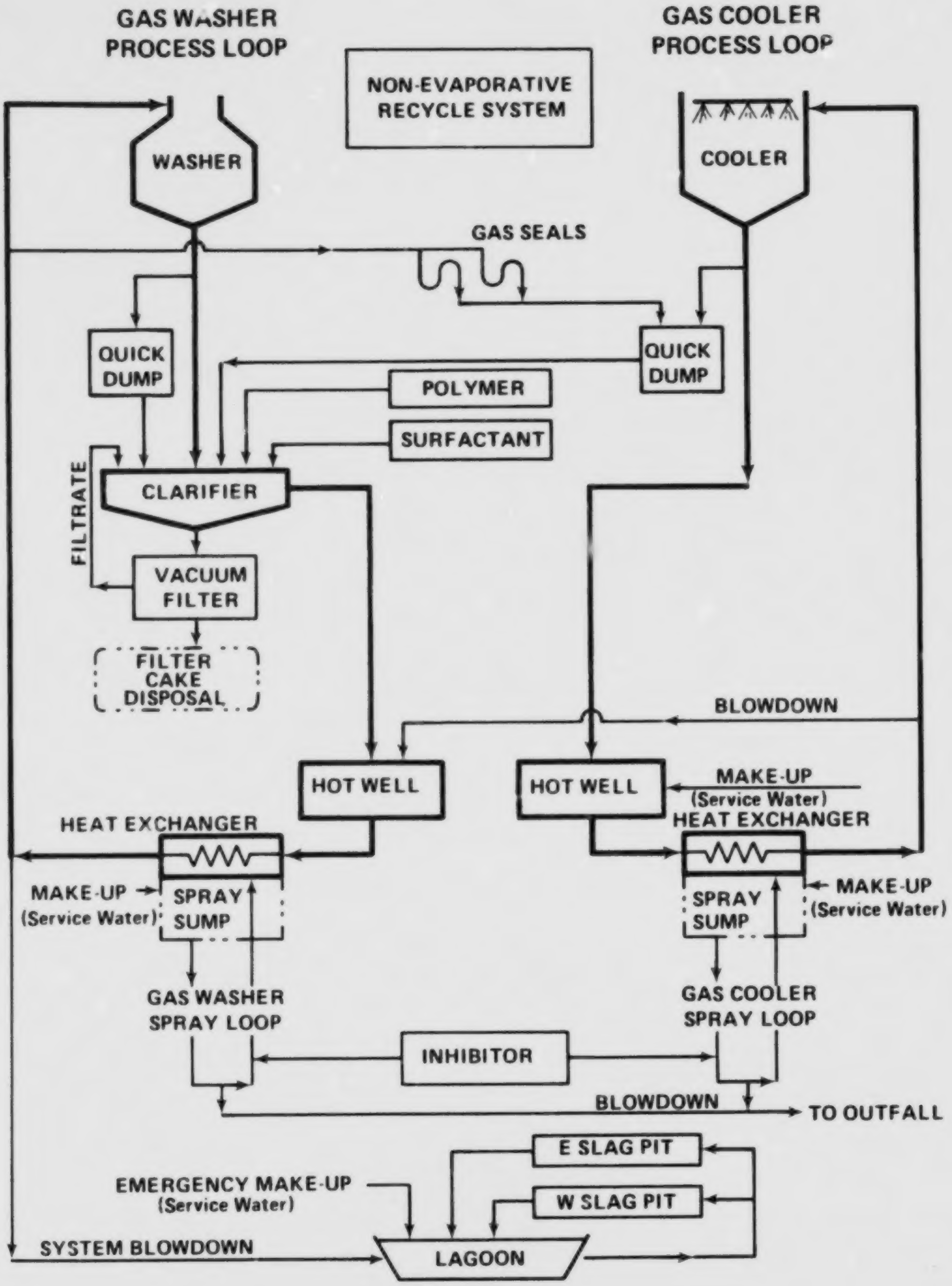
The study was designed to meet the following three objectives:

1. Evaluate nonevaporative cooling as a means of operating a tight recycle system at autogenous pH values without formation of excessive quantities of mineral scale.
2. Determine whether the system can achieve blowdown rates low enough so that the only water leaving the system is moisture in filtered sludge with the remainder totally consumed in slag quenching.
3. Ascertain the corrosive tendencies of the recycled gas-processing waters.

DESCRIPTION OF THE NONEVAPORATIVE COOLING SYSTEM

The keystone of the nonevaporative cooling system consists of two banks of heat exchangers. Tubes in the gas-cooler heat exchanger have an average wall thickness of 0.049 inches, while tubes in the gas-washer heat exchanger have an average wall thickness of 0.065 inches. The heat exchangers are wet-surface air coolers which function by forcing air and spraying plant-service (river) water over stacked bundles of tubes while the process waters pass through the tubes. Because cooling is indirect, the recycled spray water does not become contaminated and any needed blowdown can be discharged to the river.

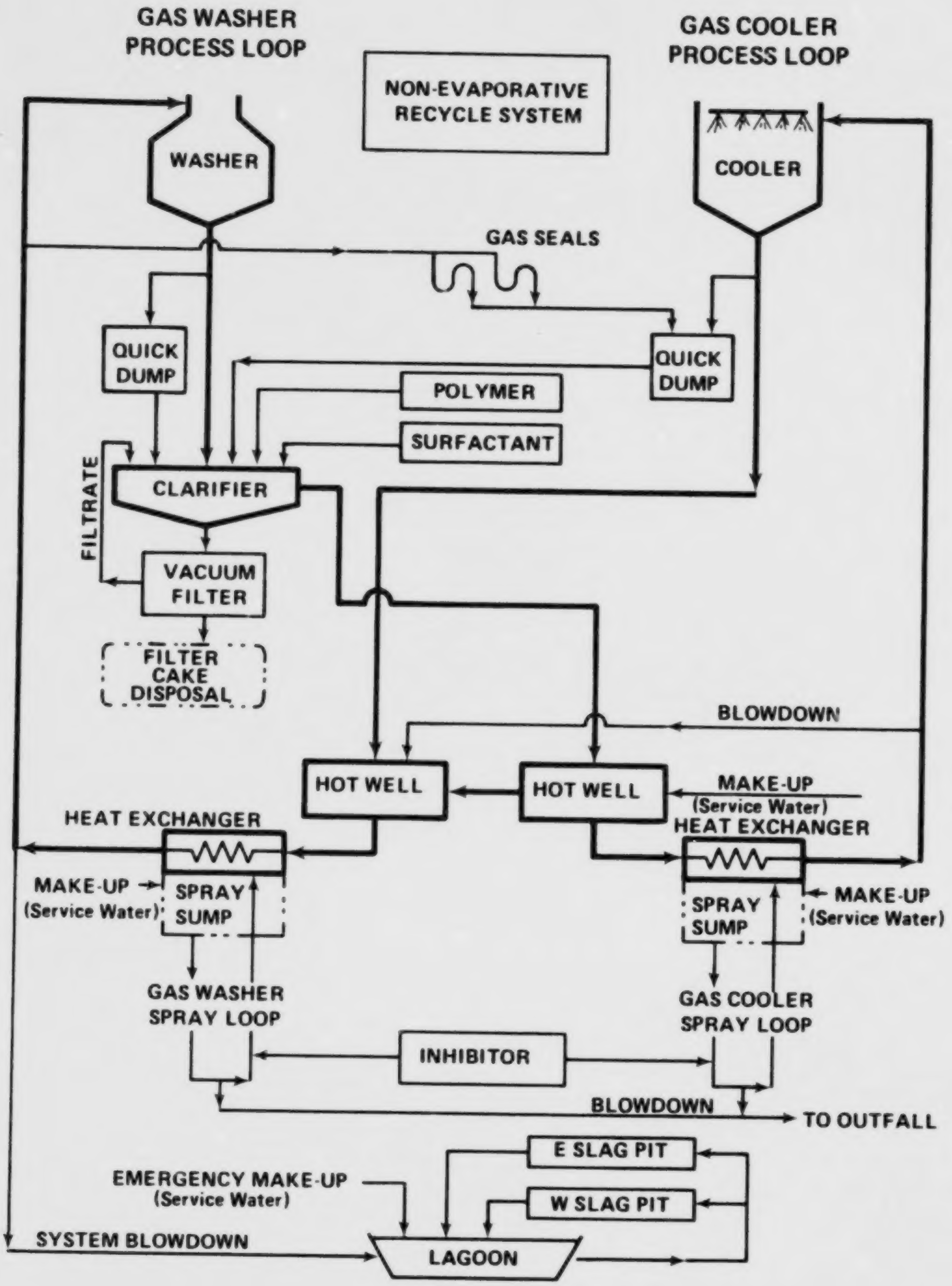
The nonevaporative system could operate in either a parallel or series mode. In parallel operation (Figure 2), gas-washer and gas-cooler process waters are isolated and individually cooled and recycled in separate loops. In series operation (Figure 3), the water stream passes alternately through the gas-washing and gas-cooling circuits.


GAS WASHER PROCESS LOOP
NON-EVAPORATIVE RECYCLE SYSTEM
GAS COOLER PROCESS LOOP
WASHER
COOLER
GAS SEALS
QUICK DUMP
QUICK DUMP
POLYMER
SURFACTANT
FILTRATE
CLARIFIER
VACUUM FILTER
FILTER CAKE DISPOSAL
BLOWDOWN
HOT WELL
HOT WELL
MAKE-UP (Service Water)
HEAT EXCHANGER
HEAT EXCHANGER
MAKE-UP (Service Water)
SPRAY SUMP
SPRAY SUMP
MAKE-UP (Service Water)
GAS WASHER SPRAY LOOP
GAS COOLER SPRAY LOOP
INHIBITOR
BLOWDOWN
TO OUTFALL
E SLAG PIT
EMERGENCY MAKE-UP (Service Water)
W SLAG PIT
SYSTEM BLOWDOWN
LAGOON

SLAG QUENCH LOOP

PARALLEL OPERATION

Figure 2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EMERGENCY MAKE-UP (Service Water)
W SLAG PIT
SYSTEM BLOWDOWN
LAGOON

SLAG QUENCH LOOP

SERIES OPERATION

Figure 3

Because all process water passes through the clarifier during series operation, this mode produces lower suspended-solids concentrations in gas-cooler process water than parallel operation. However, parallel operation was used during most of the study because it afforded more opportunity for detection and exclusion of extraneous sources of water.

RESULTS AND DISCUSSION

COMPOSITION OF PROCESS WATERS DURING TWO MONITORING PERIODS

Process waters in both loops were recycled without addition of acid, caustic, or either scale or corrosion inhibitors to determine scaling and corrosive tendencies in a tight nonevaporative system at ambient pH values. Ryznar Indices indicated a shift from corrosive to scaling tendencies as sources of extraneous water were identified and excluded from the process-water loops. The system was monitored over a period of 14 months after all identified sources of extraneous water entering the system were excluded.

Table 1 presents water analyses from the first six month of stable operation (Period 1). The average zinc concentration of 69 milligrams per litre (mg/L) in gas-washer water is attributed to the presence of sinter in the furnace burden. Gas-washer water typically exhibited pH values ranging from 7.3 to 7.5, while corresponding values in gas-cooler water were generally lower by 0.5 units.

TABLE 1. COMPOSITION OF GAS-WASHER AND GAS-COOLER PROCESS WATERS DURING PERIOD 1

Parameter	Gas-Washer Water		Gas-Cooler Water	
	Mean	Maximum	Mean	Maximum
NH_3-N, mg/L	209	260	165	204
Phenol	4.5	21.0	4.7	23.0
CN-F	12.4	47.2	12.6	39.2
Zn	69.3	350	N.A.[a]	N.A.
Pb	0.9	2.0	N.A.	N.A.
Cl	5,110	7,395	3,283	4,239
DS	10,869	14,579	7,282	9,034
SS	85.9	230	621	965
M-ALK, mg/L CaCO3	730	1,667	727	1,630
Hardness	2,065	3,331	1,415	2,551
Conduct., uS	19,010	35,500	14,539	27,800
pH units	7.29	7.87	6.76	7.21
Ryznar Index	5.08	7.02	5.88	7.66

[a] N.A. = not analyzed.

Table 2 presents water analyses data obtained during a second monitoring period (Period 2). The lower average zinc concentrations (0.2 to 0.3 mg/L) reflect the absence of sinter in the furnace burden. Water returning from the gas washer generally exhibited pH values ranging from 7.3 to 7.6, while corresponding values in water returning from the gas cooler were again typically lower by 0.5 units.

TABLE 2. COMPOSITION OF PROCESS WATERS DURING PERIOD 2

Parameter	Water From Gas Washer		Water From Gas Cooler	
	Mean	Maximum	Mean	Maximum
NH_3-N, mg/L	176	217	176	215
Phenol	0.1	0.2	0.1	0.1
CN-F	0.01	0.02	0.01	0.02
Zn	0.3	1.0	0.2	0.9
Pb	0.2	0.3	0.2	0.3
Cl	2,372	2,769	2,388	2,781
DS	5,667	6,800	5,646	6,650
SS	138	271	106	170
M-ALK, mg/L $CaCO_3$	844	1,037	842	1,063
Hardness	1,789	2,066	1,798	2,114
Conduct., uS	10,479	14,000	10,421	13,800
pH units	7.02	7.27	7.51	7.63
Ryznar Index	5.05	5.40	4.58	4.91

CONSUMPTION OF PROCESS-WATER BLOWDOWN DURING SLAG QUENCHING

Total water blowdown from the nonevaporative system consisted of a stream of gas-washer water sent to slag quenching (net blowdown) plus moisture removed with the filter cake produced from the clarifier underflow. An average net blowdown rate of 12.0 gal/THM was determined during Period 1, and all was consumed during slag quenching. It was estimated that an additional 1.3 gal/THM were removed with the filter cake.

An average net blowdown rate of 15.8 gal/THM was measured during Period 2 and, therefore, a total blowdown rate of about 17 gal/THM was sustained. The increase of about 4 gal/THM over the earlier rate is mainly attributed to the replacement of sinter by pellets in the burden. Pellets typically have a higher moisture content than sinter. Slag quenching was able to accommodate the increased blowdown rate.

SCALING TENDENCIES OF RECYCLED PROCESS WATERS IN A NONEVAPORATIVE SYSTEM

The rate of solids deposition in the heat-exchanger tubes determined whether a tight nonevaporative system could operate at autogenous pH values. Examination of the gas-washer heat exchanger revealed that solids deposition occurred at a manageable rate during Period 1. Analysis of the solids (Table 3) indicated that $CaCO_3$ (2 to 10 percent by weight) was not the principal component; instead, major identifiable substances were zinc carbonate [($ZnCO_3$), 9 to 27 percent] and calcium fluoride [(CaF_2), 4 to 28 percent]. Smaller quantities of solids were deposited in the gas-cooler tubes, possibly because of scouring by the higher level of suspended solids (ca. 600 mg/L) in gas-cooler water during parallel operation. Deposits in both heat exchangers were easily removed by high-pressure-water (hydro-jet) cleaning.

TABLE 3. COMPOSITION OF A SOLIDS DEPOSITED IN THE GAS-WASHER HEAT EXCHANGER DURING PERIOD 1

Reported Components, %		Indicated Compounds, %[a]	
Zn	24.00	CaF_2	28[b]
Ca	18.32	$CaCO_3$	10
F	13.72	$ZnCO_3$	9
CO_3	9.80	$Zn(OH)_2$	28
Si	3.72		
Al	3.21		
SO_4	1.27		
S	0.95		
Mn	0.94		
Pb	0.86		
LOI[3]	19.80		

[a] Estimated by assuming all F was present as CaF_2.

[b] X-ray analysis indicated the presence of CaF_2 or ZnS. Compound assumed to be the former on the basis of low (0.95%) S content.

[c] Loss on ignition (LOI).

The quantity and nature of solids deposited in the heat-exchanger tubes changed markedly during the next eight months of operation (Period 2). Fouling occurred at intolerable rates and frequent mechanical cleaning was necessary to alleviate the large pressure drops across the tube bundles. Analysis (Table 4) indicated that $CaCO_3$ (51 percent by weight) was the major identifiable component present in the deposits. The solids also contained 12 percent CaF_2.

TABLE 4. COMPOSITION OF A SOLIDS DEPOSITED IN THE GAS-WASHER HEAT EXCHANGER DURING PERIOD 2

Reported Components, %		Indicated Compounds, %[a]	
CO_3	43.65	CaF_2	12
Ca	26.75	$CaCO_3$	51
F	5.98	$ZnCO_3$	3
SiO_2	4.32	$MgCO_3$	6
Mg	1.71	$MnCO_3$	3
Mn	1.46		
Zn	1.43		
Al	0.78		
S_T[b]	0.32		
SO_4	0.23		
Pb	0.16		
LOI	5.26		

[a] Estimated by assuming all F was present as CaF_2.
[b] Total sulfur.

To explain the observed differences in fouling rates and deposit composition during Periods 1 and 2, it is important to note that the tendency of a sparingly soluble salt to precipitate is governed by both thermodynamics (solubility) and kinetics (rate) (8). Precipitation of a substance such as $CaCO_3$ can occur when water is supersaturated with respect to that compound. However, the rate of precipitation is kinetically controlled by availability of seed nuclei and growth of nuclei to form $CaCO_3$ crystals.

Three conditions have been identified that may affect the quantity and nature of the solids deposited in the heat-exchanger tubes.

1. Continuity of furnace operation
2. Tightness of the recycle system
3. Composition of the furnace burden

During Period 1, furnace operation was continuous and the recycle system was tight. Both process waters were continuously exposed to calcium-rich dust and CO_2 present in blast-furnace gas. Precipitation of $CaCO_3$ in the clarifier, once begun, continued because the process water remained in a supersaturated condition with respect to Ca^{2+} and CO_3^{2-} ions and kinetic equilibrium was maintained. Analyses performed with USS's modification of the Langelier Saturation Index (LSI), which describes the $CaCO_3$-scaling tendencies of the highly saline recycle water more accurately than conventional LSI values, indicated that effluent from the clarifier was saturated with $CaCO_3$ (9). Little opportunity existed to lose CO_2 from the stream as it flowed to the heat exchanger for cooling; therefore, this water stayed near saturation instead of becoming significantly supersaturated as it would if direct forced air cooling were used, and very little $CaCO_3$ scale formed in the gas-washer heat-exchanger tubes.

During Period 2, the kinetic equilibrium of $CaCO_3$ precipitation was disturbed. The furnace was banked several times and various malfunctions permitted infusion of significant quantities of service water into both process-water loops. Upon resumption of furnace operation, the recycled process water was reexposed to calcium-rich dust and CO_2 present in blast-furnace gas. Because of the time lag involved in reestablishing kinetic equilibrium of $CaCO_3$ precipitation, clarifier effluent was supersaturated with $CaCO_3$ and deposition of the salt occurred in the heat-exchanger tubes.

Successful softening in the clarifier during Period 1 was probably aided by the presence of revert sinter in the furnace burden. Zinc (Zn^{2+}) ions produced from zinc species in sinter can remove CO_3^{2-} ions from solution by forming insoluble $ZnCO_3$:

$$Zn^{2+} + CO_3^{2-} \longrightarrow \underline{ZnCO}_3$$

The presence of $ZnCO_3$ in the tube deposits is tentatively attributed to the slow precipitation rate of the salt (10). One group of investigators (11) determined that four hours were required to completely precipitate $ZnCO_3$ under the conditions studied. Because that is longer than the nominal retention time in the system clarifier (approximately 2-3/4 hours), it is probable that clarified effluent was still supersaturated with respect to $ZnCO_3$. Continued precipitation of the salt would account for its presence in deposits in the heat-exchanger tubes during Period 1. Essentially no $ZnCO_3$ was found in the tube deposits during Period 2 when the absence of sinter in the furnace burden lowered zinc levels.

Because significant amounts of available carbonic species were removed in the clarifier during both monitoring periods, the Ca^{2+} ion concentration could increase until the CaF_2 solubility limit was exceeded.

$$Ca^{2+} + 2F^- \longrightarrow \underline{CaF}_2$$

The CaF_2 was deposited in the tube bundles as a soft sediment attached to hard, underlying carbonate scale. A deposit present in the last pass of a tube bundle contained a higher percentage of CaF_2 than solids deposited in an earlier pass. Considering that the solubility of CaF_2 is not very sensitive to temperature (12), it is possible that the enrichment can be attributed to propulsion of sediment along the length of the heat exchanger tube bundles.

CORROSIVE TENDENCIES OF RECYCLED PROCESS WATERS IN A NONEVAPORATIVE SYSTEM

Test coupons indicated that the corrosiveness of the system's process waters increased as the chloride (Cl^-) ion content in the water increased due to recycling. The concentration increased to a maximum observed value of 7395 mg/L in the gas-washing water. Corrosive attack on the heat-exchanger tubes continued until several failed about 14 months after system start-up. The failed tubes were replaced and samples were cut from the corroded tubes for a comprehensive failure analysis.

The failure analysis revealed that the electric-resistance-welded (ERW) tubes had suffered severe pitting occurred on the inside surface and weld-grooving attack occurred on both surfaces. The tubes conformed to the specified SA-214 standards for ERW tubing and had been given normalizing heat treatment after welding.

Because defective metallurgy or improper finishing operations were eliminated as causative factors, the corrosive properties of the process waters were held responsible for failure of the tubes. Possible factors contributing to the corrosion include high Cl^- ion concentrations, the presence of dissolved oxygen (DO) in the process water, and carbonic acid attack due to retention of CO_2 during cooling.

Chloride ions are capable of penetrating passive films and setting up highly active, local anodic sites which accelerate corrosion (13). Normal DO concentrations (5 to 6 mg/L) may have contributed to pitting resulting from oxygen differentials (14). The DO content in water from the gas cooler was much higher than originally planned due to the pickup of oxygen from air after a 40-foot-tall degassing pipe was installed to vent carbon monoxide above ground level. Oxygen has also been claimed to exacerbate carbon dioxide related corrosion (15). Also, mechanisms have been advanced which maintain that corrosion due to ion concentration or differential aeration can be promoted and/or accelerated by the presence of deposits on heat-transfer surfaces (16).

ASSESSMENT OF THE NONEVAPORATIVE COOLING PROCESS

The study demonstrated the feasibility of nonevaporative cooling as a means of eliminating the discharge of recycled gas-processing water to public streams. Although the total blowdown rate was greater than that estimated by Troy and Crosbie (6), all blowdown in excess of moisture removed with filtered clarifier solids was consumed by evaporation during cooling of the slag produced in the furnace. Moreover, the nonevaporative system can be operated at autogenous pH values and does not need to be controlled to a pH range of 5 to 6 as recommended by Troy and Crosbie (6) or softened by the addition of an alkaline stream as recommended by Crosbie (7).

The study also demonstrated that the system's process waters have very corrosive tendencies. Possible factors contributing to the corrosion include high Cl^- ion concentrations, the presence of dissolved oxygen in the process water, and carbonic acid attack due to retention of CO_2 during cooling.

Another conclusion was that a nonevaporative system should be operated continuously and extraneous water excluded to maintain kinetic equilibrium. Loss of kinetic equilibrium leads to deposition of significant quantities of solids in the heat-exchanger tubes. Also, the composition of the furnace burden appears to affect softening in the clarifier and the nature of the tube deposits. No attempt was made to overcome scaling tendency by adding makeup water, thereby increasing blowdown to the total required for slag quenching, or to inhibit scale formation with water-treatment chemicals.

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BPT TO BAT BY INTEGRATED PROCESS CONTROL
BLAST FURNACE BLOWDOWN MINIMIZATION ACHIEVES BAT COMPLIANCE

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ABSTRACT

The LTV Steel Company, at its Cleveland East facility, received a new NPDES permit which included BAT discharge limits for its #1-4 blast furnace recycle system. The recycle system was operating at BPT levels. To achieve BAT limits it was determined that an intensive blowdown minimization program would have to be instituted. (Blowdown minimization is an alternative method of BAT compliance rather than alkaline chlorination). Conventional blowdown minimization methods were not possible or economically feasible at this facility and, therefore, an alternative method was needed. LTV Steel was concurrently involved in implementing an Integrated Process Control (IPC) program for more efficient operation of all its production facilities. Fortunately, the IPC program was perfectly suitable for the #1-4 blast furnace blowdown minimization program. Application of the IPC program is the topic of this paper.

This paper details the results of work conducted on elimination of blast furnace blowdown. The results include application of statistical methods for recognizing recycle system variances in flow rates and resulting system operation. Recognization of these variances allows identification of the cause of the variances and allows operating personnel (both treatment plant and blast furnace) to investigate and institute corrective measures. Timely corrective measures provide better control of recycle system operations at both the treatment plant and blast furnace. More efficient operation allows reduction of system blowdown and is progress toward meeting BAT flow allowances and discharge limitations. In addition, the paper discusses ancillary benefits in system operations, including increased operator awareness of system mechanics, cost reduction, and communication between treatment plant, blast furnace, and outside contractor personnel.

NOTE: Although certain actions described in this paper were carried out by Republic Steel prior to the commencement of joint operations with J&L Steel, Incorporated under the name LTV Steel, all references in the paper are to LTV Steel. Also, the program, Integrated Process Control (IPC) was formed by the combination of the Republic Statistical Process Control (SPC) Program and the J&L Integrated Quality Control System (IQCS). All items which would have been referred to as SPC are now referred to as IPC.

INTRODUCTION

LTV Steel operates a vast complex of coke, iron and steelmaking facilities along the Cuyahoga River in Cleveland, Ohio. The complex is comprised of the prior Republic Steel Cleveland District and former J&L Cleveland Works. The principal products of this complex are hot bands and cold roll strip. The complex, at present, has the capability of operating six blast furnaces. All furnaces are operated using recycle systems with treatment through sedimentation and clarification. When the NPDES permit was reissued for the Nos. 1 and 4 blast furnace recycle system on the west side of the River, BAT effluent limitations were applied along with minor adjustments for water quality considerations. The new effluent limitations were much more stringent than the prior BPT limitations and therefore additional treatment measures would be required to achieve compliance. EPA-BAT model technology suggested the installation of alkaline chlorination equipment for treatment of blowdown from the existing recycle facility. Due to the expected capital cost, operating costs, and difficulities associated with an alkaline chlorination system, other alternatives were investigated. The most obvious alternative was to reduce the recycle system blowdown to a flow of less than the BAT model flow rate of 70 gallons per ton (gpt) (116 gpm at rated capacity) for the 1 & 4 blast furnace system. A flow rate at this low level would allow certain compliance with the BAT limitations imposed through the NPDES permit. Shown below is a table illustrating the NPDES limitations applied to this blast furnace treatment system.

In addition to achieving BAT level blowdown rates, a target of zero recycle system blowdown was self-imposed on the 1 & 4 recycle system by the Environmental Control Department. By improving the recycle system to the point where zero blowdown could be achieved at will, the system blowdown in the future could be strictly regulated to achieve optimum system chemistry and significantly reduced effluent pollutant loadings.

The achievement of the BAT model blowdown rate and, also intermittent periods of zero blowdown, were accomplished at the LTV Cleveland 1 & 4 blast furnace recycle system through the use of Integrated Process Control (IPC) theories and physical improvements made in response to discoveries made through IPC. The application of IPC to the 1 & 4 recycle system is the subject of the remainder of this paper.

DISCUSSION

The table below illustrates the NPDES permit effluent limitation applied to the 1 & 4 blast furnace recycle system.

	BPT KG/DAY MONTHLY AVE	DAILY MAX	BAT KG/DAY MONTHLY AVE	DAILY MAX
AMMONIA (N)	206.8	413.7	60.1	180.4
CYANIDE (T)	20.7	43.6	3.42	6.84
PHENOL (4AAP)	8.6	20.9	0.40	0.80
LEAD	—	—	0.34	1.03
ZINC	—	—	0.51	1.54

As can be seen from the above table, there is a wide margin between BPT limitations and the new BAT limitations. When the present blowdown reduction program was first initiated in September of 1983. The average blowdown rate was approximately .4 million gallons per day. This correlates to approximately 280 gpm or 168 gpt. To achieve the BAT flow rate, reduction of blowdown rate by approximately 60% would be required. This task was exceptionally difficult because this 1 & 4 Blast Furnace recycle system was already a very tight system with an approximate 93% recycle rate. In order to reduce the blowdown to the target rate, an intensive program identifying sources of extraneous water flow into the recycle system was required. In the past when recycle systems were not set at such high recycle percentages, identification of extraneous water sources was not as difficult as it would be in this instance. Therefore, a method of systematically identifying occurences of intrusion of extraneous water sources was required.

When the Environmental Control Department identified the need for a systematic method of identifying intrusions of extraneous water sources, LTV Steel was concurrently developing an Integrated Process Control program for the entire corporation.

Due to the attributes of IPC, the customers of LTV Steel requested the use of IPC in the production of the products they intended to purchase. To cause their requests to have a more powerful impact, LTV Steel's participation as a supplier depended upon the adoption of an IPC program.

Integrated Process Control (IPC) is a method for identifying critical physical parameters within operating systems, developing data to show the average and acceptable range of these parameters, and determining optimum operating conditions. IPC was also to be used as a diagnostic tool to predict if and when certain types of maintenance should be conducted and also to predict when malfunctions might occur so that maintenance could be promptly performed. In summary, the goal of IPC is to achieve the ability to make economically sound decisions about actions or conditions which affect the operating process.

A system is said to be operating in statistical control only when all variations within the system are caused by known and/or controlled sources. Therefore, for a system to be coralled into statistical control the first step is to detect and eliminate special causes of variation (e.g., extraneous water sources discharging into the blast furnace recycle system). Once the system is in statistical control the reactions of the system to change is predictable and further improvements can be made with knowledge of their impact. In total then, IPC can be used to improve product quality or increase operating efficiency (e.g., achievement of zero blowdown).

The first step in implementing the IPC program at the 1 & 4 recycle system was the development of initial control charts. These control charts contain graphical representations of the mean operating level of the recycle blowdown (Mean Control Limit), an upper acceptable range with an upper limit corresponding to the upper control limit and a mirrored lower control limit.

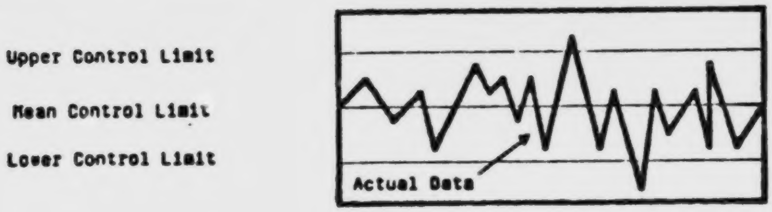
The initial Mean Control Limit (MCL or $\bar{x}$) was calculated using the average of days of blowdown flow rate values. The blowdown rates for this system were calculated on a per turn basis and then were averaged each day to generate an average blowdown rate for the day. Once the $\bar{x}$ was calculated then the upper and lower control limits could be calculated using the following formulas:

$$\text{Upper Control Limit} = \bar{x} + 1.023\ (\bar{R})$$
$$\text{Lower Control Limit} = \bar{x} - 1.023\ (\bar{R})$$

Where $\bar{R}$ is the average of the ranges between the highest and lowest blowdown flow rates recorded each day.

The upper, lower, and mean control limits were drawn on the control charts and then actual blowdown flow rate data was plotted on the charts. A simplified version of a control chart is shown below.

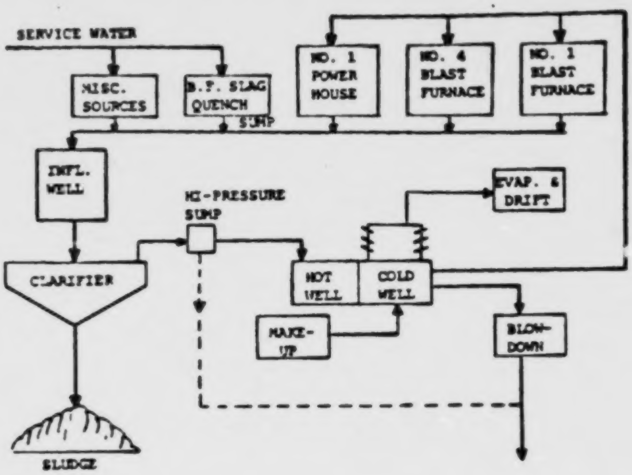
Sample Control Chart



Once upper, lower, and mean control limits are calculated and drawn on the control charts and then actual data plotted, the control charts can be reviewed for system characteristics. Review of the control charts begins by looking first for data points which fall outside the control limits. When this occurs there is a presumption that there is a variation in the system caused by an action outside of the control of the system. In the case of the 1 & 4 blast furnace recycle system these variations would be assumed to be either intrusions of extraneous water or unauthorized taps from the system. Upon the excursion of a data point beyond a control limit an investigation was immediately made to determine the cause. In this manner the extraneous water source or tap could be quickly identified. Secondary review of the charts is intended to identify if there occurred six consecutive data points above or below the mean control limit. This situation indicates a possible trend and was also considered an out of control occurrence and something to be investigated. Finally, if the range for any one day was considerably in excess of the average range ($\bar{R}$) another occurrence for investigation was discovered.

When physical modifications were made to the system in response to extreme variations, as denoted by the control limits, no changes were made in plotting of control chart data for 20 days. Following 20 days of data gathering, after physical changes had been made, new control limits were plotted. By this method rolling control limits, upper, lower and mean, could be utilized.

Application or development of IPC is not complex in theory. However, when a mathematical theory is to be applied to a physical system, complexities arise which must be controlled in order for the application to be beneficial. Such was the case with the 1 & 4 blast furnace system. The 1 & 4 blast furnace recycle system appears in the schematic below.


SERVICE WATER
MISC. SOURCES
B.F. SLAG QUENCH
SUMP
NO. 1 POWER HOUSE
NO. 4 BLAST FURNACE
NO. 1 BLAST FURNACE
INFL. WELL
HI-PRESSURE SUMP
EVAP. & DRIFT
CLARIFIER
HOT WELL
COLD WELL
MAKE-UP
BLOW-DOWN
SLUDGE

Prior to initiation of the IPC program, the blowdown rate from the treatment sytem was set in manual mode. Manual mode was used for blowdown control because the main influent well to the clarifiers was maintained on level control through the use of constant speed pumps. When the level in the well was high the pumps were activated and the well would be pumped down. A pump would then shut off and reduced flow would be going to the clarifier. This created a surge in the hot and cold well of the cooling tower. The surge in the hot well could not be handled and the hot well would overflow uncontrolled to the high pressure sump and then out of the recycle system directly to the outfall station. This overflow would not be recorded by the flow recorders on the treatment plant control board. Only the outfall station would record the total blowdown rate (hot well overflow and controlled blowdown). This was not an accurate method of controlling blowdown rate. Additionally, if the blowdown rate was artificially set too high, the system would need to make up river water to maintain hydraulic balance. This was not a steady state system which is required for application of IPC. To alleviate this problem, an automatic flow/level control device was installed and used exclusively at the main influent well.

Once an automatic flow device was installed, data needed to be generated for the IPC program. To generate data that could be used for charting, the flow totalizer on the flow meter at the treatment plant was used to calculate average blowdown rates per turn on a gallon per minute basis. When the initial data gathering began and plotting on the control charts was initiated, no pattern of data was determined to be useful. However, as data gathering continued, it was noted that the time for recording average blowdown rates for each shift was different. To develop data which would be useful, a standard time within each shift was set for making the blowdown measurement. The time of each blowdown reading was logged to account for swings or missing of the standard time at which flow is to be read. That is, if nine hours had been calculated on a previous turn and seven hours had been used the following turn, this would be shown in the calculation of average blowdown rate. This minor adjustment made a vast improvement in the reliability of the flow data being used on the IPC charts.

The first six or seven weeks of calculations were performed by supervisory personnel with data gathering and calculations later being completed by plant operating personnel. To assist treatment plant operating personnel, a simple calculation sheet was developed. (This sheet is shown as Attachment 1). The calculations needed to show the average gpm flow rate and were carried out using the following formula:

$$\begin{array}{lllllll}\text{Current} & & \text{Previous} & & \text{No. of Min.} & & \text{Average}\\ \text{Totalizer} & - & \text{Totalizer} & \div & \text{Between} & = & \text{Blowdown}\\ \text{Value} & & \text{Value} & & \text{Readings} & & \text{Per Turn (gpm)}\end{array}$$

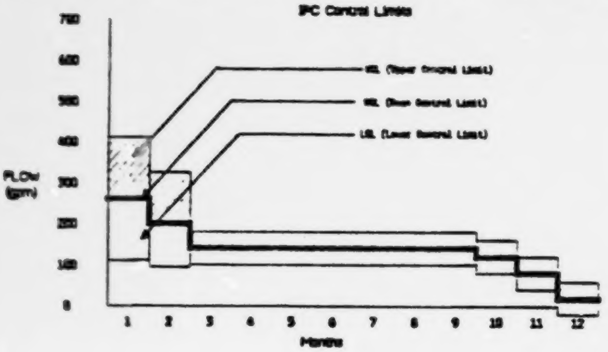
To ease the mathematical requirements on operating personnel, each operator was issued an inexpense hand held, solar powered calculator. Providing the personnel with these inexpense calculators was probably the single most useful thing done to insure accuracy of IPC data. Once operating personnel were confident in doing calculations required by IPC, each turn was provided with the materials for IPC and full IPC data gathering and control responsibility was placed on them.

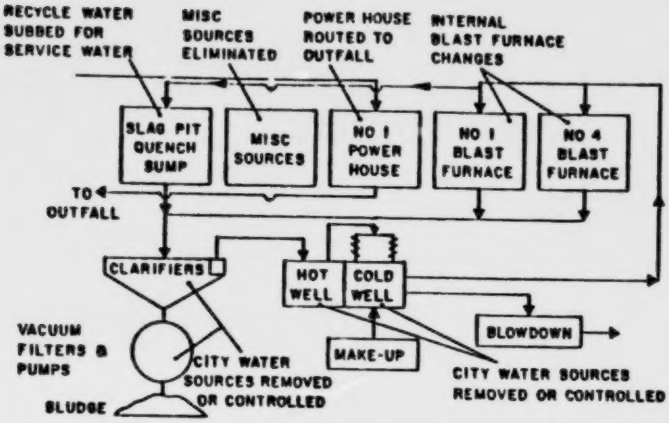
The flow calculations that each turn completed were listed along with those for the prior eight hour turn. Because each turn crew would check the previous turn, plant operating personnel would know if the previous turn had not performed their IPC work properly, and the latter turn would develop typical steel plant criticism. This caused each turn to become more conscious of their responsibilities and to become more conscientious about their fulfillment. Once the operating personnel understood the reasons for developing IPC data, they were provided with instructions that if large variations occurred, that is, changes which would exceed the upper or lower control limits on the IPC chart, the system needed to be investigated to determine the source of the large variation. When these variations occurred in the system the operator would first proceed to investigate the known treatment plant water sources in an attempt to account for the variance. If no source was found within the treatment plant, the operator would contact blast furnace personnel to identify if any water use changes had occurred within the blast furnace system. By requiring operating personnel to investigate changes immediately, the problem of recollection or mistaken recollection was alleviated. Rapid response allowed rapid identification of extraneous water sources.

Numerous modifications within the recycle system were made by using the IPC program. In the treatment plant itself some operating practices and conditions came to light that effected the blowdown rate. For instance, the use of bearing lubricating water, pump gland water and seal water on pumps were converted from either city water to recycle water or the use of city water was stringently controlled. Control of the use of city water reduced the effect of this extraneous water on the recycle system and allowed for major blowdown reductions. These were the only major changes made at the treatment plant itself. However, as in all plants, there were general plant clean up operations which were adjusted with reduction of blowdown in mind. To regulate and account for city water flows or other general plant flows, flow monitors were installed within pipe lines. Through this method intrusion of extraneous city water into the recycle system was checked. In addition, the installation of these flow meters helped eliminate and narrow the area for investigation of other unknown sources when further out of control variations occurred.

At the blast furnace itself, changes were made through use of the IPC program. This included replacing service water with blast furnace recycle water for slag quench operations. The flow of quench water, prior to its being converted from service water to recycle water, was an extreme source of extraneous water. When quench operations were occurring the service water valve was open wide and no control by blast furnace operators was effected. The excess quench water would be discharged to the quench sump and then routed to the main influent sump. Addition of this quench water to the recycle system would cause an extreme variation beyond the upper control limit. Rapid investigation of the variance led to discussions with the blast furnace supervisor responsible for the quench operation. This discussion led to an investigation of the source of the quench water. It was quickly determined that service water was being used for quench rather than recycle water as previously assumed. Once recycle water was used for quench, the blowdown rate was reduced drastically. In addition, the use of recycle water for quench improved the system chemistry. The rapid discovery on the control charts of the large variance in the recycle enabled the quench water problem to be quickly and easily solved. This may not have been the case had IPC and control charts not been employed.

The graph below shows the reduction of blast furnace blowdown as illustrated by changing control limits. The step points on the chart indicate recalculation of control limits and generally correspond to physical modifications made within the recycle system. The schematic diagram below briefly describes the areas where physical modifications were made to the recycle system.

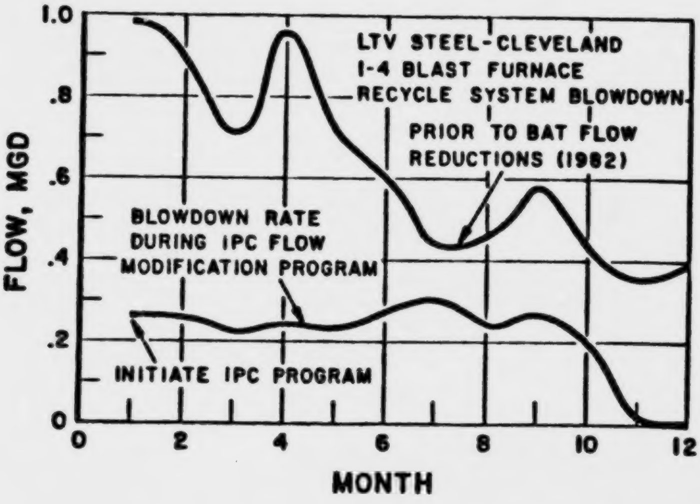



1-4 BLAST FURNACE RECYCLE SYSTEM MODIFICATIONS

RECYCLE WATER SUBBED FOR SERVICE WATER
MISC SOURCES ELIMINATED
POWER HOUSE ROUTED TO OUTFALL
INTERNAL BLAST FURNACE CHANGES
SLAG PIT QUENCH SUMP
MISC SOURCES
NO 1 POWER HOUSE
NO 1 BLAST FURNACE
NO 4 BLAST FURNACE
TO OUTFALL
CLARIFIERS
HOT WELL
COLD WELL
BLOWDOWN
VACUUM FILTERS & PUMPS
CITY WATER SOURCES REMOVED OR CONTROLLED
MAKE-UP
CITY WATER SOURCES REMOVED OR CONTROLLED
SLUDGE

As the recycle system approached statistical control, the system stabilized and greater operator control could be exercised. The more stable the system the more R was reduced. Reduction of R reduced the upper and lower control limits. This made the IPC chart a much more sensitive tool. This more sensitive tool helped in identifying smaller and smaller extraneous water sources. As the smaller sources were being identified and the system was stabilized to a greater degree, even more attention was given to the IPC program. The IPC program then shifted from control of the treatment plant to control of the whole furnace gas cleaning system. As control of the whole gas cleaning system became more necessary for blowdown reduction, communication between blast furnace personnel and treatment plant personnel increased in importance. Development of this communication between treatment plant and blast furnace personnel proved to be a significant benefit of the IPC program in addition to the reduction of blast furnace blowdown.

As the flow was reduced to below the goal of 116 gpm it was determined that continued flow reductions would be pursued. The figure below shows the overall reduction of blowdown rate.



As can be seen, the actual blowdown flow rate as of Month 12 (August, 1984) was at or near zero. A blowdown rate of less than 10 gpm at this facility is now maintained consistently. Additionally, there has been little problem with maintaining an intermittent zero blowdown rate. Chemistry within the system can be maintained through the use of water treatment chemicals with only a minor chemical use increase (scale inhibitor and polymer) and most importantly the required BAT NPDES limitations were met in a timely manner at minimum cost.

CONCLUSION

The LTV Steel Cleveland 1 & 4 blast furnace recycle system was able to achieve BAT effluent limitations by blowdown reduction. It is doubtful that the blowdown reduction program would have been as successful or efficient had the Integrated Process Control method not been employed. In addition to the achievement of the required effluent limitations, the IPC program acted as a mechanism to increase operating personnel motivation and involvement in a system improvement program. Finally, the IPC program allows operating personnel to consistently maintain extremely low blowdown rates necessary for continued compliance with the NPDES BAT effluent limitations.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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*The name was changed to
Integrated Process Control
after these charts were
created.

ATTACHMENT I

*Statistical Process Control

DAILY BLOWDOWN FLOW

DATE TIME		CURRENT INTEGRATOR NO.	−	PREVIOUS INTEGRATOR NO.	=	TOTAL GALLONS x 100	÷ 480 =	AVERAGE G.P.M. PER TURN
	4							
	12							
	8							
	4							
	12							
	8							
	4							
	12							
	8							
	4							
	12							
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DEVELOPMENT OF SINGLE STAGE BIOLOGICAL OXIDATION TREATMENT PLANT FOR COKE PLANT WASTEWATER

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ABSTRACT

A basic question existed about whether the results of bench scale laboratory test results of a single stage biological oxidation reactor could be applied to a full scale facility treating by-product coke plant wastewater. Of particular concern was the reduction of concentration of phenol, ammonia, and cyanides (thiocyanate).

Engineering design factors were developed from the bench scale research. Isolated as critical factors were: (1) design of a facility large enough to permit the biological oxidization to function efficiently; and (2) design of facility components which permitted control of influent quality to the reactor to be held within a narrow band of concentrations.

The projected waste stream was characterized; a process was developed; engineering design of components was accomplished; a comprehensive operator training program was developed and applied; and start-up results are described.

"...considerable but not insuperable difficulties (exists) in the purification of (gas liquor wastes) by bacterial means; on the other hand, the oxidation of these wastes by chemical means can only be effected at a prohibitive cost." (1)

That statement was made by Frankland and Silvester 77 years ago. Some of these concerns exist today in spite of considerable analytical work on and operational experience with biological oxidation wastewater treatment plant facilities. A number of reasons have been cited to account for limitations of this treatment scheme for by-product coke plant wastewaters. Some of these reasons are: (1) limitation of the biological process itself to reach Best Available Treatment (BAT) Limitations; (2) limits within which biological treatment can be expected to treat a given parameter; (3) the order of reactions within a biological oxidation system and the sequence in which the reactions occur and which reaction or reactions may be the limiting factor(s); (4) the relationships among operating parameters such as mixed liquor solids, hydraulic and sludge residence time, and treatment performance. (2)

A fundamental fact remains, that most biological oxidation treatment works for coke plant wastes were simply not designed and built to produce an effluent quality to meet BAT limitations. There are sound reasons for this fact not the least of which is physical space limits on where such a plant can be situated to serve a by-product plant.

This paper will focus upon engineering design considerations for a single stage biological oxidation reactor to treat coke plant wastes.

In 1979, the Research and Development Department of National Steel Corporation conducted a laboratory investigation to ascertain the limits of a single stage reactor phenol-nitrification system to comply with BAT effluent limitations. (3)

Among the major conclusions from this research were: (1) complex cyanides in concentrations of 10 - 100 mg/l appear to pass through the biological process unaltered; (2) the biological process has the capability of controlling the discharge of priority organic pollutants, influenced by the hydraulic and sludge residence times; (3) incremental nitrogen loadings to the reactor can be tolerated for reasonable periods of time provided reactor conditions, especially pH and dissolved oxygen, are maintained at or near optimum levels without severely disrupting the biological activity; (4) free cyanide severely inhibited nitrification, but concentrations up to 12 mg/l did not affect the thiocyanate organisms; (5) the addition of light oil to the reactor in concentrations up to 2,000 mg/l did not appear to effect the biological reactions; (6) wastewater with phenol concentrations up to 5,000 mg/l can be effectively treated.

Out of these findings two very important engineering design considerations emerge:

1. The elements of the biological oxidation treatment plant must be designed with the capability to handle the process flow and provide adequate residence time for treatment. In direct terms, make the plant large enough.

2. The system must be designed to compensate for variations in flow and to provide a uniform concentration of pollutants so the biological system is not shocked.

The expected performance of a waste stream requiring reductions in phenol, ammonia, sulfides, and thiocyanate concentrations is presented in Table 1.

TABLE 1: TYPICAL INFLUENTS AND RESULTANT EFFLUENTS

Parameter	Influent Quality	Effluent Quality
Phenol	Up to 1,000 mg/l	0 - 10 ppb
NH_3	Up to 500 mg/l	0 - 10 mg/l
Thiocyanate	300 mg/l	1 - 5 mg/l
Sulfides	30 mg/l	< 0.30 mg/l
TSS	100 mg/l	< 30 mg/l
pH	10	7.5

The task was presented to National Engineers and Associates, to design a single stage reactor biological oxidaton wastewater treatment facility to treat wastes from the sources shown in Figure 1. titled "Process streams comprising the influent to the biological wastewater treatment plant".

The predicted characterization of the process flow streams comprising the influent to the biological oxidation treatment facility are shown in Table 2. This table shows the components of each waste stream shown in Figure 1.

TABLE 2. CHARACTERIZATION OF THE PROCESS FLOW STREAMS COMPRISING THE INFLUENT TO GRANITE CITY STEEL WASTEWATER TREATMENT PLANT

PARAMETER	PROCESS**										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
FLOW, GPD	36,000	250	21,600	88,380	43,200	17,280	14,400	72,000	86,460	90,000	469,570
BOD	175	57,150	2,020	6,300	TA*	1,300	2,000	1,200	370	---	1,275
COD	265	71,400	2,955	7,475	TA*	1,900	3,000	1,700	790	---	2,010
AMMONIA	5	TA*	350	9,310	TA*	30	130	270	12	---	85
CYANIDE	50	TA*	345	74	TA*	50	345	1,400	18	---	15
OIL AND GREASE	10	TA*	10	100	TA*	30	10	20	10	---	20
PHENOL	5	TA*	560	1,610	TA*	360	560	5	125	---	380
TDS	1,500	109,000	1,480	22,700	TA*	50	1,480	200	480	---	5,140
TSS	10	1	10	200	TA*	15	10	50	40	---	60
SULFIDE	5	3,936	22	30	TA*	35	22	300	TA*	---	2
SCN	20	40,300	20	665	TA*	460	20	10	17	---	150
CHLORIDES	150	---	120	12,000	TA*	11,515	120	120	100	---	2,550
pH	6-8	6-8	8-11	9-11	6-9	8-11	6-8	6-8	6-7	---	9-11

*TA - TRACE AMOUNTS

PARAMETER: ALL UNITS = mg/l.
EXCEPT WHERE NOTED.

** PROCESSES (1) THROUGH (9) - SEE FIGURE 1
PROCESS (10) - OTHER SOURCE (MAINLY AMMONIA STILL)
PROCESS (11) - INFLUENT TO TREATMENT PLANT.

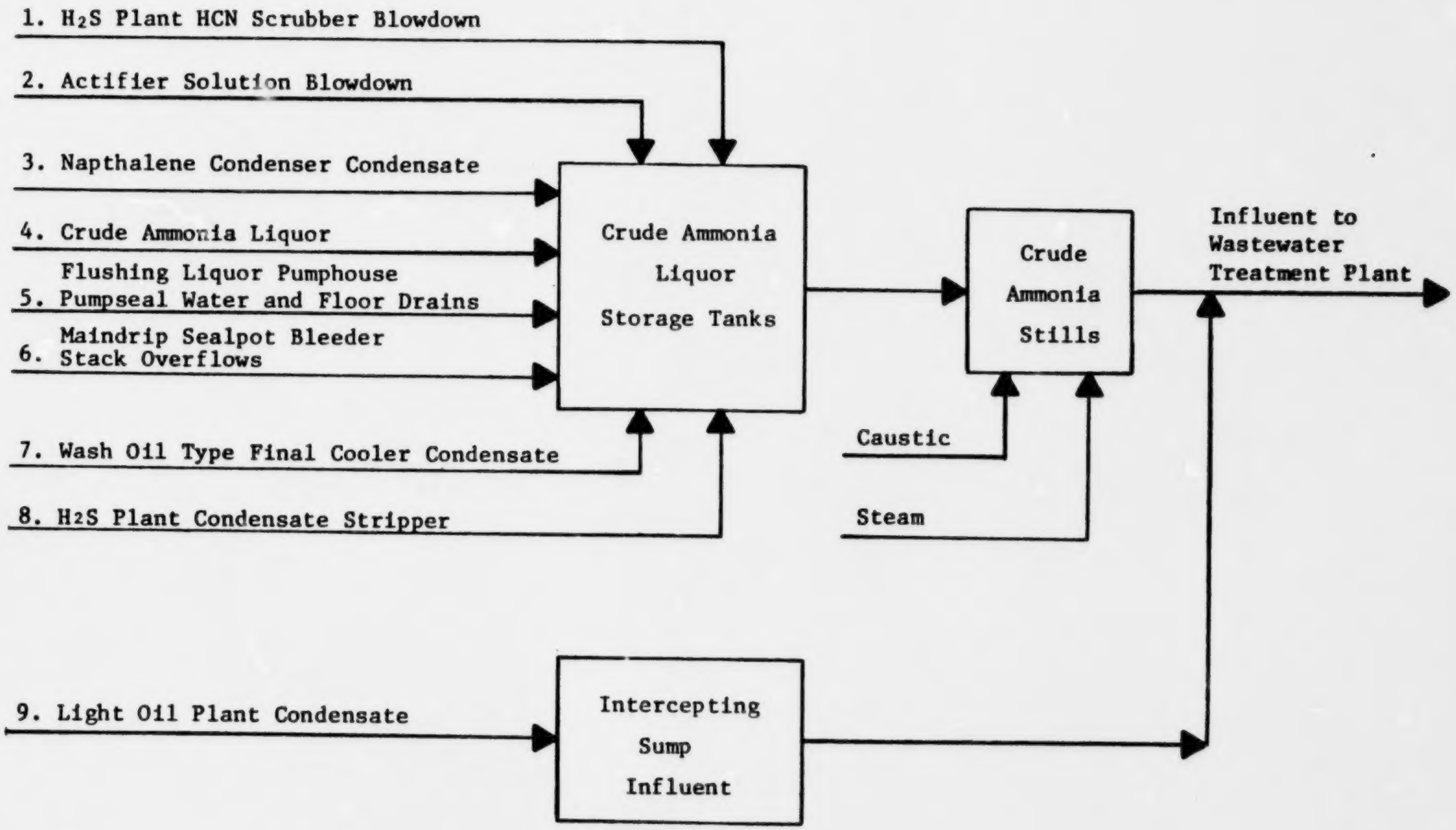
1. H_2S Plant HCN Scrubber Blowdown
2. Actifier Solution Blowdown
3. Napthalene Condenser Condensate
4. Crude Ammonia Liquor
5. Flushing Liquor Pumphouse Pumpseal Water and Floor Drains
6. Maindrip Sealpot Bleeder Stack Overflows
7. Wash Oil Type Final Cooler Condensate
8. H_2S Plant Condensate Stripper
9. Light Oil Plant Condensate
Crude Ammonia Liquor Storage Tanks
Crude Ammonia Stills
Caustic
Steam
Intercepting Sump Influent
Influent to Wastewater Treatment Plant

Figure 1. Process streams comprising the influent to the biological wastewater treatment plant

The resultant influent to the treatment facility is shown in Table 3., below.

TABLE 3. CHARACTERIZATION OF THE INFLUENT TO THE BIOLOGICAL OXIDATION WASTEWATER TREATMENT FACILITY

Parameter	Predicted Influent Quality
Flow, GPD	469,570
BOD	1,275 mg/l
COD	2,010 mg/l
Ammonia	85 mg/l
Cyanide	15 mg/l
Oil and Grease	20 mg/l
Phenol	380 mg/l
TDS	5,140 mg/l
TSS	60 mg/l
Sulfide	2 mg/l
SCN	150 mg/l
Chlorides	2,550 mg/l
pH	9 - 11

The characterization of the waste stream was provided by the client's by-product coke plant consultant, and some of the critical values turned out to be low as can be seen in examples of operating data shown later.

After careful consideration of the factors bearing upon the engineering design decisions which had to be made, the treatment process was conceptualized. The work product of that conceptualization produced the process flow diagram shown in Figure 2.

It was considered necessary to provide emergency storage tanks for untreated effluent ahead of the biological oxidation reactor in case of unforeseen conditions which could cause a malfunction in the system.

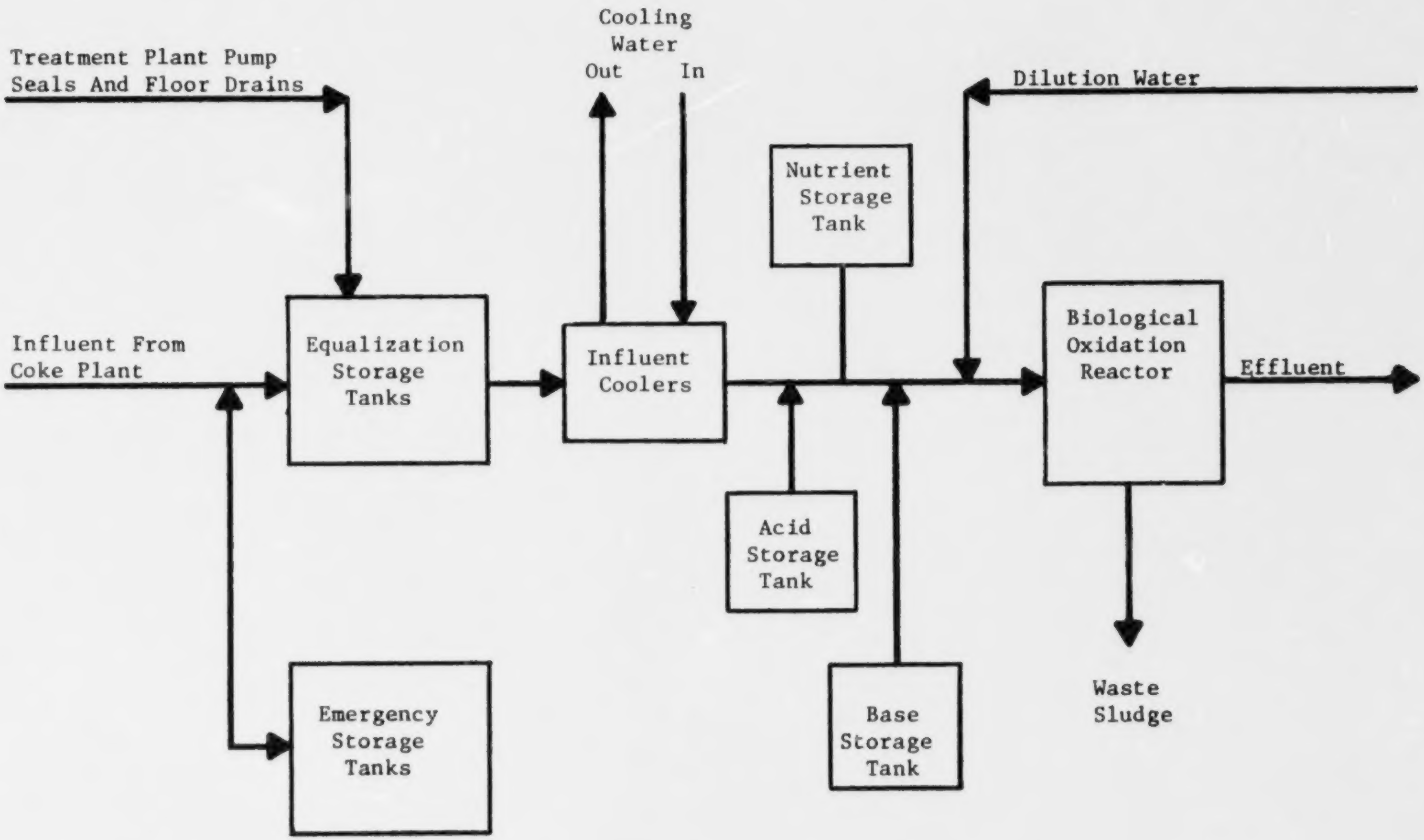
Treatment Plant Pump
Seals And Floor Drains
Influent From
Coke Plant
Equalization Storage Tanks
Emergency Storage Tanks
Cooling Water
Out
In
Influent Coolers
Nutrient Storage Tank
Acid Storage Tank
Base Storage Tank
Dilution Water
Biological Oxidation Reactor
Effluent
Waste Sludge

Figure 2. Biological oxidation wastewater treatment plant - process flow diagram

Second, because the biological process works best when it is not subject to sudden changes in influent concentrations of the parameters to be treated, equalization storage tanks were included. This permits blending of the waste stream which varies widely in strength on a daily basis.

It was also determined that the waste stream arrived at the treatment facility at a temperature which was too high for the bio-mass to tolerate; therefore, influent coolers were provided.

Storage tanks were provided for tempering or adjusting quantities of nutrients, acid, and base to be added on demand.

A source of dilution was provided as a further precaution against concentrations which would "shock" the bio-mass and render it passive.

Finally, the single stage biological oxidation reactor was provided with a means of removal of excess sludge. The biological reactor was designed and constructed as two cells operating in parallel. The reason for the two cells was to build in flexibility for by-product plant operation and to improve the efficiency of aeration and mixing within the reactor.

Figure 3., a schematic diagram of the treatment facility shows the layout of the plant. The functions of emergency storage tanks and equalization basin were combined thereby saving space and capital cost.

Throughout the entire design process, the two overriding engineering considerations were:

1. Make the plant large enough.

2. Provide an operation to dampen or decrease "shocks" to the bio-system due to large variations in concentrations of pollutants in the waste stream.

In addition to the engineering design considerations, a complete manual of operation and systems maintenance was prepared. By itself this would be considered rather routine; however, this manual was supplemented by a training program for operating personnel. Topics of mathematics, laboratory procedures, and theory of the biological oxidation process were covered at a level conducive to operator understanding and use.

Table 4. lists the major topics of the training program which were presented in a classroom setting complete with lecture, discussion, homework, and proficiency examinations.

TABLE 4. OUTLINE OF OPERATOR'S TRAINING PROGRAM

1. Terminology and Definitions.
2. Characterization of the Wastewater.
3. Description of Biological Wastewater Treatment.
4. Process Description.
5. Detailed Explanation of the System Components. How They Operate, Function Each Performs, and How to Use Each One.
6. Basic Review of Mathematics Needed For Operation.
7. Sampling Procedures For Process Control.
8. Laboratory Testing Procedures.
9. Record Keeping.
10. Process Trouble-Shooting.
11. Personal Hygiene and Safety.
12. Emergency Procedures.

An earlier reference was made to daily variations in effluent quality observed during start-up. This was true for virtually every parameter; however, only phenol is shown here for illustrative purposes. The reader is cautioned that these are start-up data before the treatment facility had reached its full efficiency; nevertheless, the results are very impressive.

Figure 4. shows the phenol concentrations entering the equalization tanks.

Figure 5. shows the phenol concentrations entering the biological oxidation reactor from the equalization tanks. Note the dampening effect on the phenol concentrations compared to the concentrations entering the equalization tanks. As the operators gained more experience, the variations were decreased even more. The nature of the process does not permit perfectly uniform concentrations from the equalization tanks. Fortunately, such level of control is not necessary for excellent operation. What is sought here is operation within a relatively narrow band of concentrations.

Figure 6. shows the concentrations of phenol discharge from the single stage reactor.

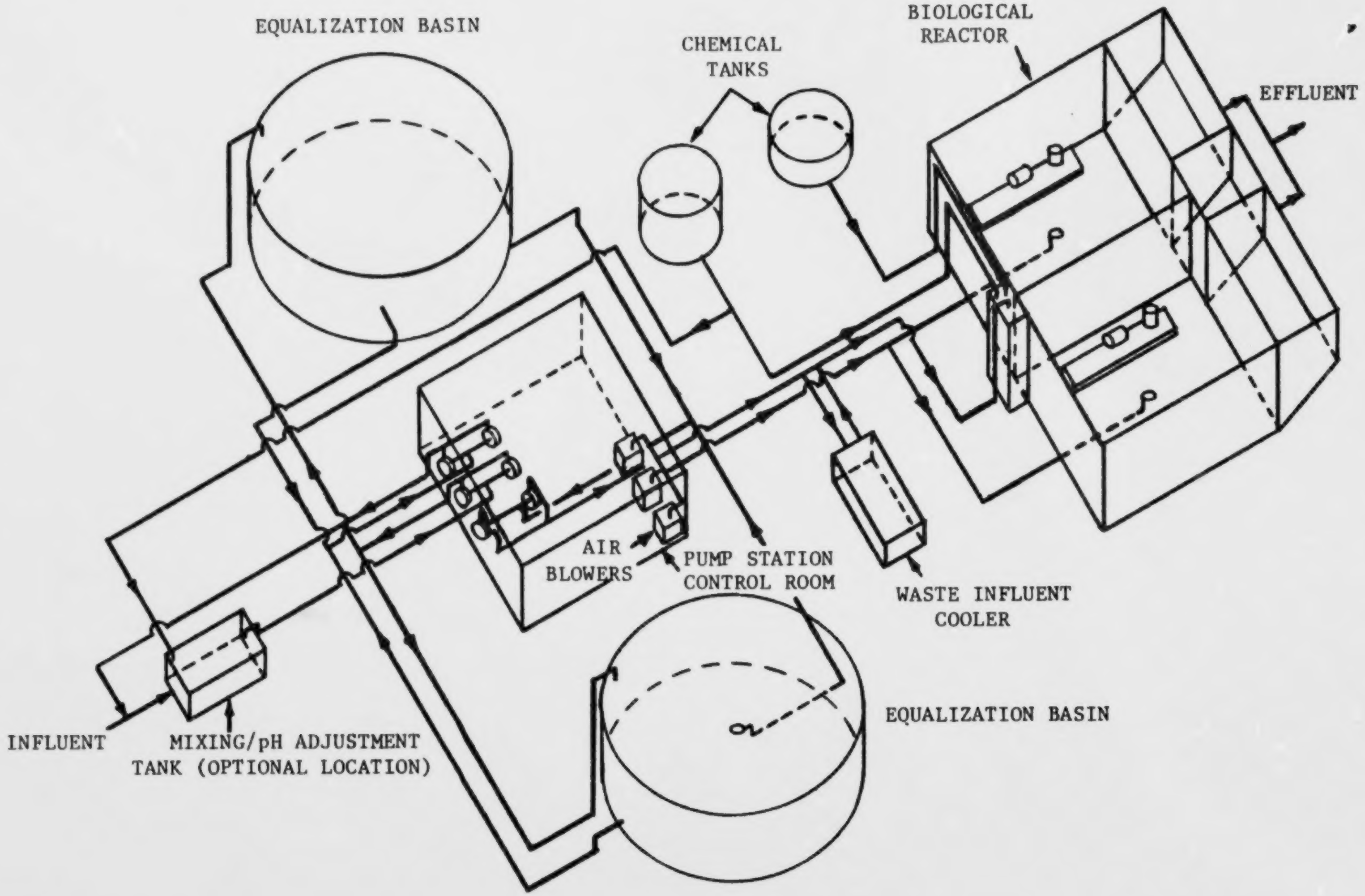
EQUALIZATION BASIN
CHEMICAL TANKS
BIOLOGICAL REACTOR
EFFLUENT
AIR BLOWERS
PUMP STATION CONTROL ROOM
WASTE INFLUENT COOLER
INFLUENT
MIXING/pH ADJUSTMENT TANK (OPTIONAL LOCATION)
EQUALIZATION BASIN

Figure 3. Schematic diagram of single stage biological oxidation wastewater treatment plant

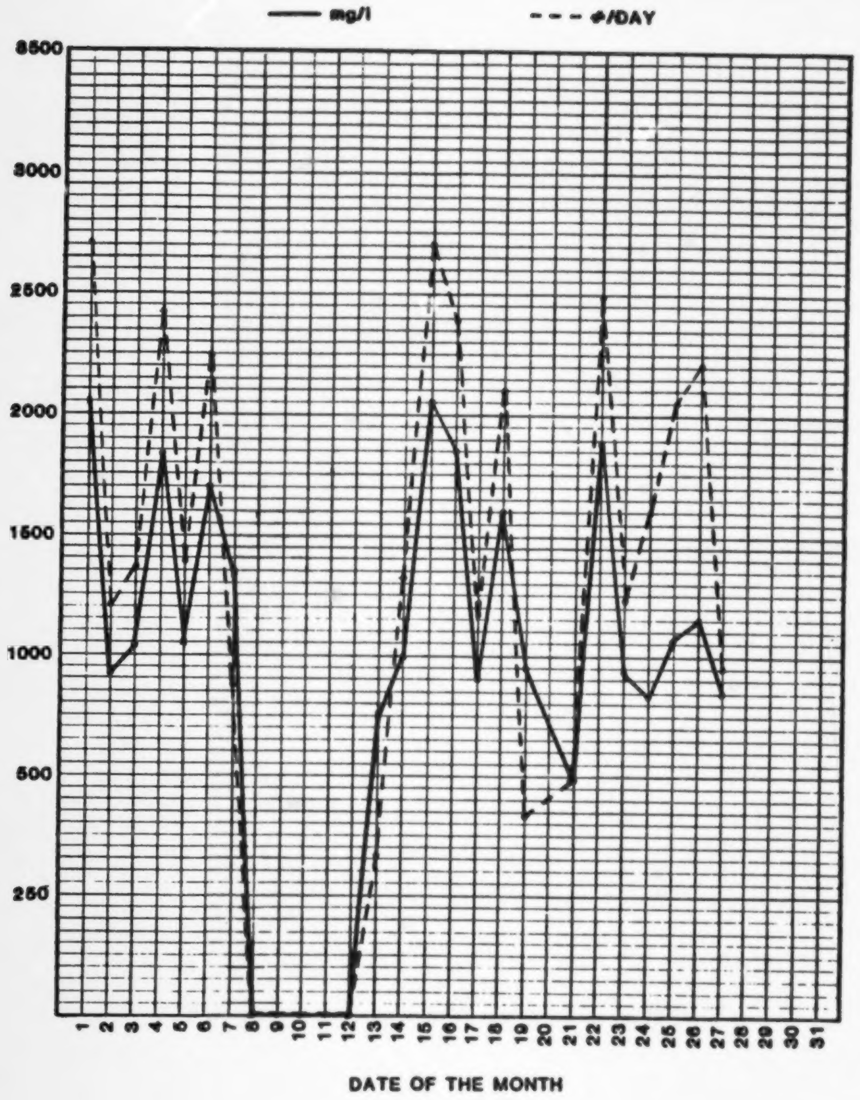

Figure 4. Phenol - concentrations entering the equalization tanks

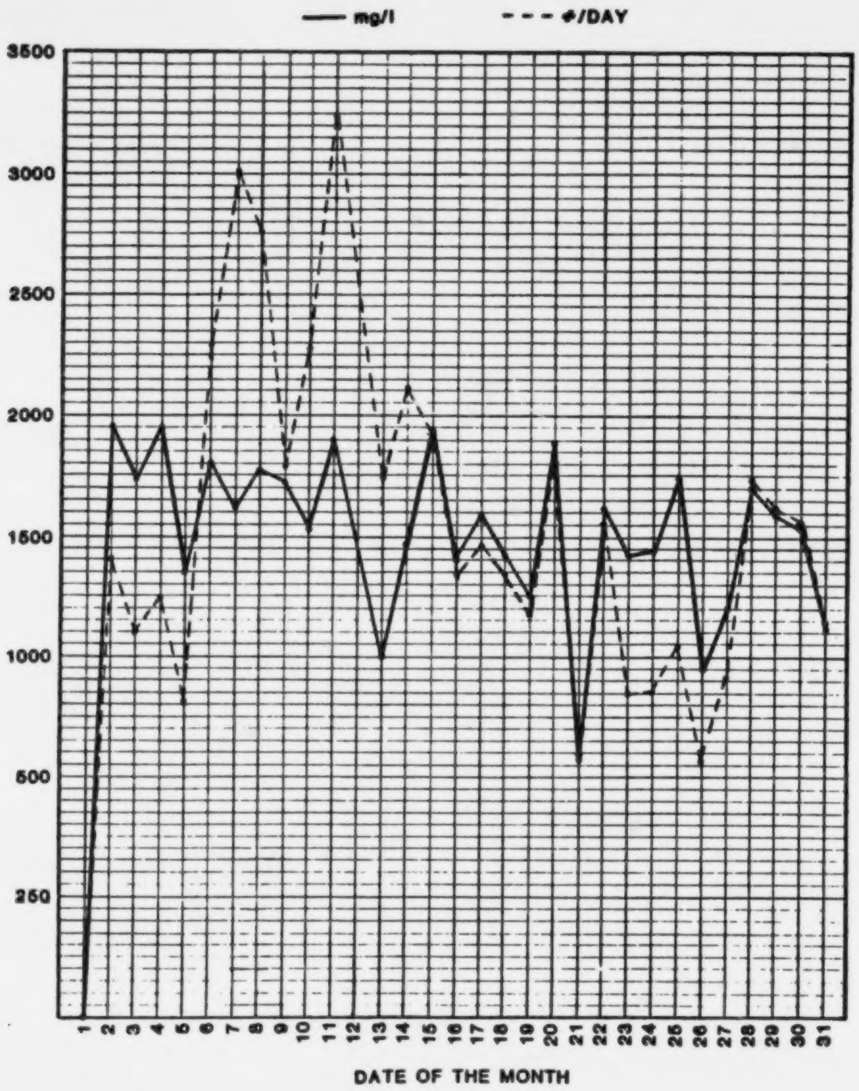

Figure 5. Phenol - concentrations entering the biological oxidation reactor from the equalization tanks

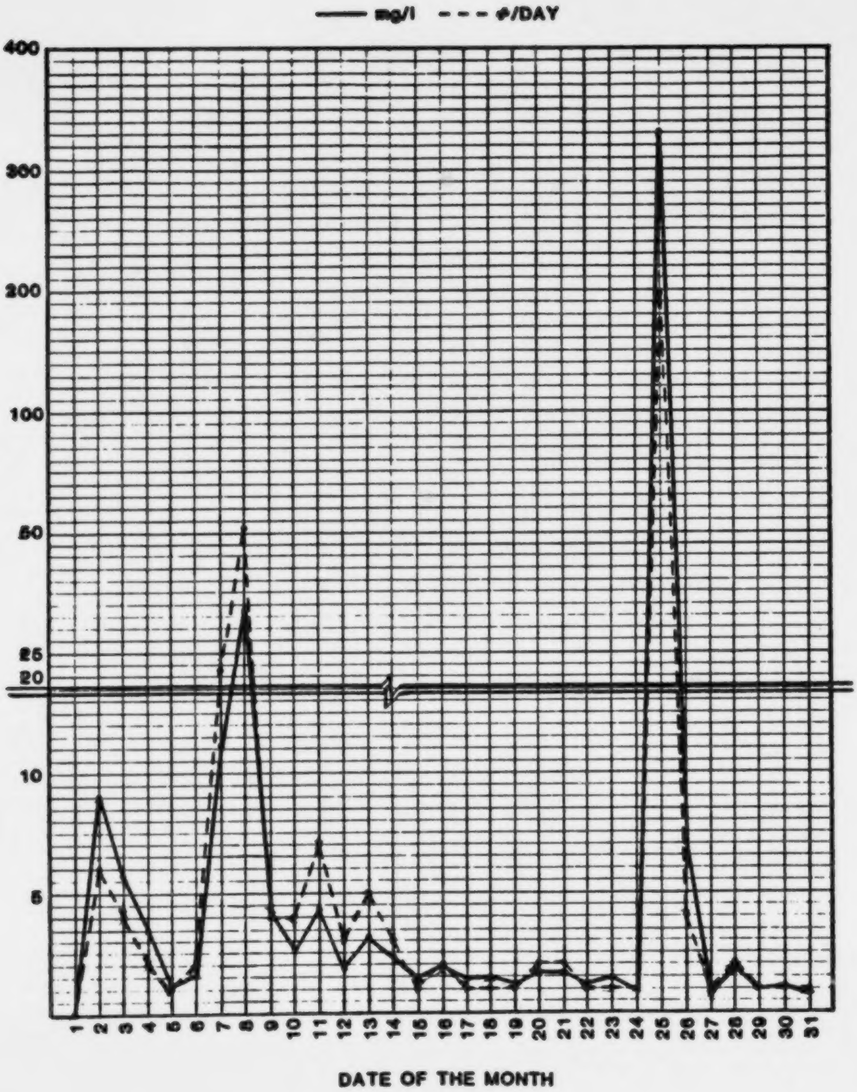

Figure 6. Phenol - concentrations discharged from the single stage reactor

The start-up seed for the biological process was excess sludge from a nearby activated sludge process in a petrochemical plant. This seed was enhanced by the addition of a specialized blend of bacteria commercially available and produced specifically for the degradation of hydrocarbon type wastes. This product is comprehensive to many hydrocarbon materials ranging from phenolic, cyclic chemicals to straight chain oils and grease.

This seed insured excellent phenol removal early in the start-up process.

After about 60 days of start-up operation, nitrifier microbes were added to begin the reduction of ammonia concentrations. The nitrifier microbes did not naturally establish themselves.

The mixed liquor suspended solids (MLSS) concentration was steadily increased to over 10,000 mg/l.

Many engineering design questions are not addressed here due to the limitations of time.

The single stage reactor has proven to be a success in actual day to day operation in meeting the expected reductions in the targeted pollutant concentrations.

The work described in this paper was not funded by the U. S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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PILOT SCALE EVALUATION OF AN INNOVATIVE BIOLOGICAL TREATMENT SYSTEM ON HIGH-STRENGTH COKE PLANT WASTEWATER

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ABSTRACT

This paper describes results obtained during a 30-week pilot study conducted at Armco's Ashland, Kentucky, 3,000 TPD coking facility from December 1983 - June 1984. The subject study evaluated the innovative Burns and McDonnell Treatment System (BMTS), treating an undiluted slipstream from the total coke plant wastewater discharge. The BMTS is an oxidation ditch style activated sludge system with a unique intrachannel clarifier design. It has been accepted by U.S. EPA as an "innovative and alternative" technology. A pilot-scale, trailer-mounted BMTS was utilized as a central component of the extensive pilot system employed.

The BMTS was shown to exhibit excellent removal rates for many commonly measured pollution indicators, including phenol (99.7%), BOD (94+%), COD (70+%), TOC (87+%), hydrogen sulfide (100%), cyanide (40+%), thiocyanate (80+%), and oil and grease (87+%). Extensive performance data will be presented for these and other parameters. It is shown that treatment for phenol prior to the biosystem is unnecessary. Removal rates of up to 1000+ mg/l of ammonia nitrogen were shown, indicating the potential feasibility of replacing fixed ammonia stills with biological nitrification. A conceptual process schematic for a full-scale nitrification plant is presented, including projected capital and operating costs.

INTRODUCTION

Armco's Ashland plant is located in Ashland, Kentucky, on the Ohio River. The plant produces metallurgical coke and coking by-products, and consists of two batteries. One battery is a 3.7 meter, 76 oven, under-jet battery. It was constructed in 1953 and underwent a major rehabilitation in 1973. The other is a 5 meter, 70 oven, gas gun battery, which was rebuilt in 1978. Total production capacity is considered to be 3014 tons dry coke per day. During this study, the coke plant was operating at or near capacity, averaging 2966 tons/day from December 1983 - June 1984. The by-product plant was installed to handle approximately 45,000,000 SCF per day of coke oven gas. The following by-products are recovered for sale or internal use: coke oven gas, tar, light oil, ammonia, tar acids, sulfur, coke breeze, and buckwheat breeze.

The total coke plant wastewater is currently partially pretreated and then discharged to the municipal sewage treatment plant of the City of Ashland. Because of sharply escalating pretreatment costs associated with upcoming pretreatment standards(1), the uncertain effectiveness and continued availability of the City's system, and increasing treatment rates charged for the City's service, the option of full self-sufficiency through complete treatment on-site and direct discharge to the Ohio River is being considered. In order to assess the technical alternatives and the associated economics of becoming a direct discharger, pilot studies were undertaken.

Armco has extensive experience with the conventional form of completely-mixed, extended aeration activated sludge treatment system for coke plant wastewater through the construction and three-year operation of such a system at its former Hamilton Coke Plant. Details of this system and its performance have been reported earlier (2, 3, 4).

For these pilot studies it was decided to evaluate the Burns & McDonnell Treatment System (BMTS). The BMTS is a U.S. EPA accepted "innovative and alternative" technology which is an oxidation ditch style extended aeration activated sludge system with an unique intrachannel clarifier design. It was reported to offer potential advantages over the more conventional system in the form of substantially reduced capital and operating costs.

DESCRIPTION OF THE PILOT SYSTEM

RAW FEED STREAM CHARACTERISTICS

Full-scale pretreatment of the raw weak ammonia liquor includes: (1) phenol removal by solvent extraction; (2) decarbonization to liberate noncondensables such as CO_2, H_2S, and HCN; and (3) steam distillation (free stills) and absorption to concentrate and purify the residual ammonia solution. Typical characteristics of the slipstream taken from the total coke plant process discharge during the pilot study are shown in Table 1.

Additional pretreatment (for fixed ammonia removal and pH and temperature control) was provided by components of the total pilot system. Also, during the major portion of the study, the feed flow was further amended by the addition of raw tar acid (phenol) to simulate shutdown of the full-scale phenol removal system. Typical characteristics of the actual feed to the BMTS are also presented in Table 1.

TABLE 1: TYPICAL RAW FEED STREAM CHARACTERISTICS

Parameter	Coke Plant Total Discharge	To Pilot System
BOD_5, mg/l	490	1300
COD, mg/l	2000	3000
TOC, mg/l	475	950
Phenols, mg/l	40	400
Ammonia N, mg/l	1100	500
Total Cyanide, mg/l	1.0	1.0
Thiocyanate, mg/l	660	800
Hydrogen Sulfide, mg/l	70	70
Oil & Grease, mg/l	45	50
Suspended Solids, mg/l	60	110
pH, range	6.9-9.1	6.5-11.0
Temperature, °F	122	77
Alkalinity to pH 7.0 (mg/l as $CaCO_3$)	575	1350

BMTS MOBILE PILOT PLANT

The BMTS Mobile Pilot Plant (MPP) is a trailer-mounted, fully-operational wastewater treatment unit suitable for on-site testing of municipal wastewater and any industrial wastewater amenable to treatment by the activated sludge process. The MPP incorporates the same basic equipment and method of operation used in full-scale BMTS installations. Illustrations describing the BMTS concept and operation are contained in Figures 1-3.

The MPP (see Figure 4) employs the activated sludge process in an oxidation channel configuration. Full-size, fine-bubble type air diffusers are located throughout the aeration channel. The mixed liquor is pumped around the channel by two hydraulic motor-driven propeller type mixers. The mixers are mounted on a common guide rail, one above the other, near the wastewater inlet end of the channel. After passing through the aeration channel, the mixed liquor flows under the intrachannel clarifier. At the clarifier, the flow and some of the mixed liquor solids pass up through the baffle plates at the bottom of the clarifier into the quiescent zone inside the clarifier. The solids settle in the lower region of the clarifier, and eventually drop back into the flowing mixed liquor beneath the baffle plates. Clear supernatant continues to flow upward, and is removed through orifice pipes located a few inches below the water surface. After passing under the clarifier, the mixed liquor continues around the end of the channel, where it again blends with the influent stream and completes a circuit around the channel at the submerged mixers.

The net volume of the aeration zone is 7,270 gallons. The clarifier provides a total settling area of 28 square feet. This area is equally divided into four separate settling compartments by two interior partition walls. Each settling compartment contains one effluent orifice pipe. By using slide plates to plug one or more, individual orifice pipes, the surface overflow rate can be varied.

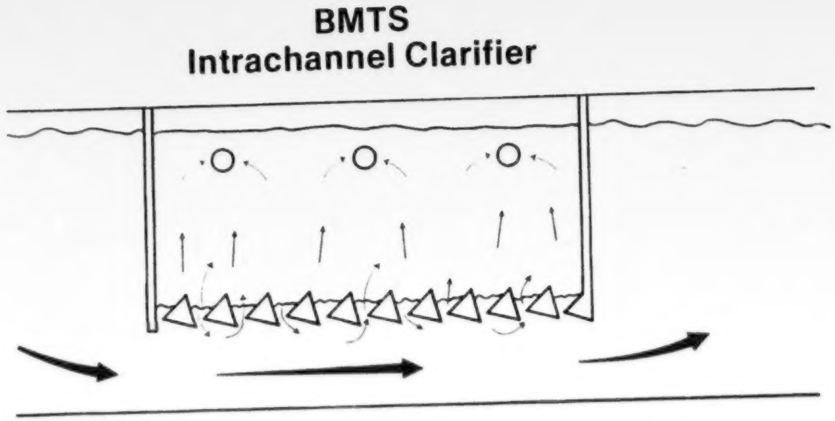

BMTS
Intrachannel Clarifier

Figure 1. Some of the circulating wastewater flows up into the clarifier.

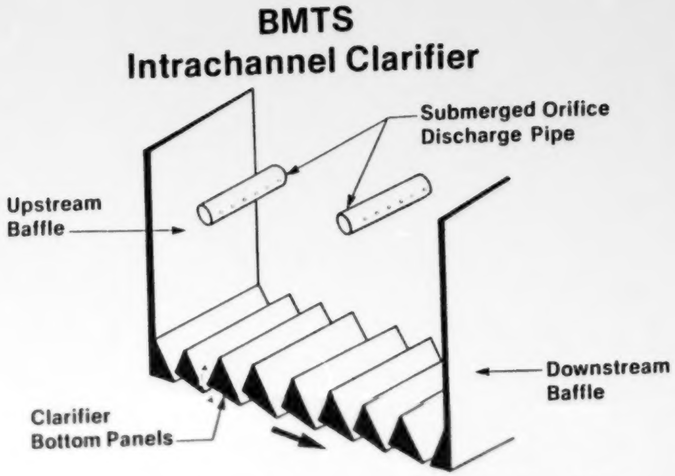

BMTS
Intrachannel Clarifier
Submerged Orifice Discharge Pipe
Upstream Baffle
Downstream Baffle
Clarifier Bottom Panels

Figure 2. In the non-mechanical clarifier, solids fall back through the bottom baffles while discharge pipes remove cleaned water.

Figure 3. Wastewater circulates continuously around the basin.

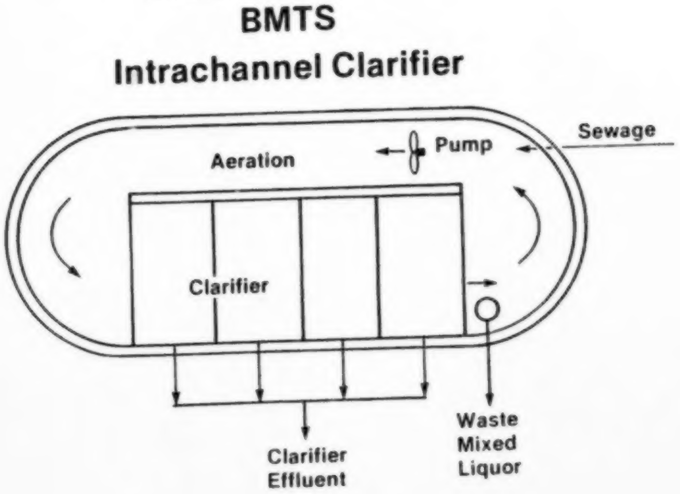
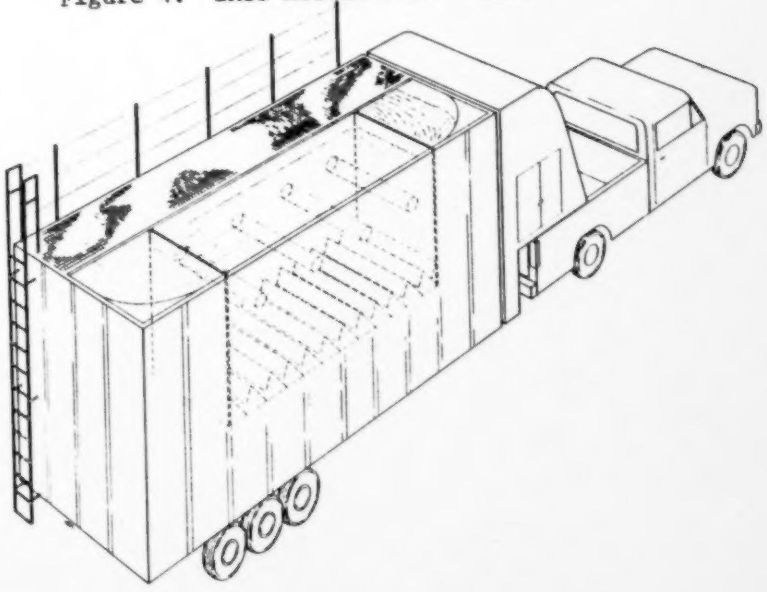

BMTS
Intrachannel Clarifier
Aeration
Pump
Sewage
Clarifier
Clarifier Effluent
Waste Mixed Liquor

Figure 4. BMTS Mobile Pilot Plant.



Two positive displacement type air blowers are provided with the MPP. Each blower is rated to provide 70 scfm. One blower serves as a standby unit. Sludge is wasted from the MPP by blowdown of mixed liquor directly from the aeration channel. The volume of mixed liquor wasted is measured by filling a calibrated collection tank on a batch basis prior to draining to the sewer.

AUXILIARY SYSTEMS

A schematic diagram of the complete pilot testing system is shown in Figure 5. All wastewater sources from the coke plant are discharged to a shallow basin for equalization and blending of the various sources prior to final discharge. Wastewater was continuously pumped to the pilot system from the equalization basin effluent.

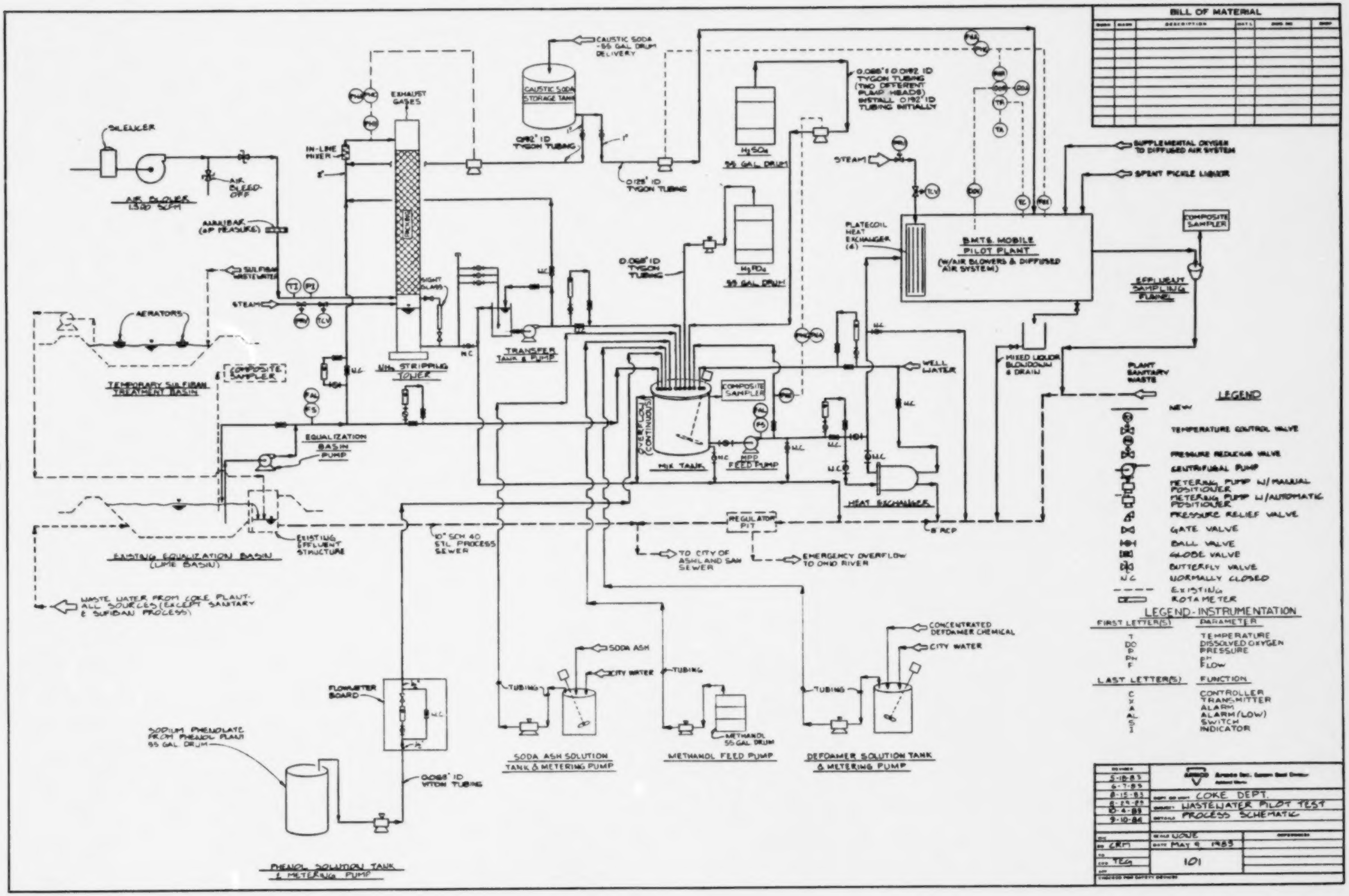
Wastewater from the basin was initially treated in a pilot ammonia stripping column. The coke plant operates only a free leg ammonia still. Therefore, the pilot stripping column was required to reduce the ammonia concentration into the biological treatment unit for process control. Caustic soda was automatically added to the stripping column influent to maintain a selected pH. Steam was added to the column to improve the stripping efficiency. A 1,500 scfm air blower was provided for counter-current air stripping of the ammonia. Tower internals consisted of loose-fill packing, stainless steel distributor and packing support plates, and the air and steam distributor nozzles. The ammonia-stripped wastewater was then pumped to a 150 gallon mix tank used for blending the various chemicals and dilution water with the wastewater prior to pumping to the BMTS-MPP.

A shell and tube heat exchanger was installed to cool the MPP influent when necessary. Four plate coil heat exchangers were installed in the corners of the MPP tank for steam heating of the mixed liquor when required. It was necessary to operate the plate coils frequently from December through March in order to maintain the desired mixed liquor temperature.

A 500 gallon bulk storage tank was provided for 50% caustic soda. Two automatic pH control loops were set up for metering the concentrated caustic soda. One system was for raising the pH of the influent stream to the ammonia stripping column. The other automatic system was used to control pH in the MPP aeration basin during the nitrification testing phase.

Concentrated sulfuric acid, when needed, was automatically metered from 55 gallon drums into the mix tank to neutralize the wastewater prior to entering the MPP. The acid metering pump speed was paced by a controller to maintain the desired aeration basin pH. Concentrated phosphoric acid was metered from 55 gallon drums into the mix tank to supply phosphorous as a biological nutrient. The feed rate was manually set to maintain an addition rate near one pound of phosphorous per 100 lbs. of COD fed(5).

In order to simulate phenol concentrations representative of expected future full-scale operations, supplemental addition of phenol to the wastewater test stream was necessary. This was accomplished by metering by-product phenol to the mix tank from storage drums. The metering rate was manually adjusted each day based on the influent phenol concentration measured from the composite influent sample collected the previous day. Due to the high variation in the strength of the stock phenol and difficulties encountered in maintaining a constant phenol flow, accurate control of the phenol concentration in the MPP influent proved to be difficult.



BILL OF MATERIAL
DESCRIPTION
SILENCER
AIR BLOWER 1300 SCFM
AIR BLEED-OFF
ANNUBAR (ΔP MEASURE)
SULFIBAN WASTEWATER
STEAM
AERATORS
TEMPORARY SULFIBAN TREATMENT BASIN
COMPOSITE SAMPLER
IN-LINE MIXER
EXHAUST GASES
SIGHT GLASS
NH3 STRIPPING TOWER
EQUALIZATION BASIN PUMP
EXISTING EFFLUENT STRUCTURE
EXISTING EQUALIZATION BASIN (LIME BASIN)
WASTE WATER FROM COKE PLANT- ALL SOURCES (EXCEPT SANITARY & SULFIBAN PROCESS)
10" SCH 40 STL PROCESS SEWER
CAUSTIC SODA -55 GAL DRUM DELIVERY
CAUSTIC SODA STORAGE TANK
0.192" ID TYGON TUBING
0.125" ID TYGON TUBING
TRANSFER TANK & PUMP
H2SO4 55 GAL DRUM
H3PO4 55 GAL DRUM
0.088" ID TYGON TUBING
0.088" & 0.192" ID TYGON TUBING (TWO DIFFERENT PUMP HEADS) INSTALL 0.192" ID TUBING INITIALLY
OVERFLOW (CONTINUOUS)
MIX TANK
COMPOSITE SAMPLER
MPP FEED PUMP
REGULATOR PIT
TO CITY OF ASHLAND SAN SEWER
EMERGENCY OVERFLOW TO OHIO RIVER
HEAT EXCHANGER
WELL WATER
PLATECOIL HEAT EXCHANGER (4)
BMTS MOBILE PILOT PLANT (W/AIR BLOWERS & DIFFUSED AIR SYSTEM)
MIXED LIQUOR BLOWDOWN & DRAIN
SUPPLEMENTAL OXYGEN TO DIFFUSED AIR SYSTEM
SPENT PICKLE LIQUOR
COMPOSITE SAMPLER
EFFLUENT SAMPLING FLUME
PLANT SANITARY WASTE
8" RCP
N.C.
FLOWMETER BOARD
SODIUM PHENOLATE FROM PHENOL PLANT 55 GAL DRUM
0.088" ID VITON TUBING
PHENOL SOLUTION TANK & METERING PUMP
SODA ASH
CITY WATER
TUBING
SODA ASH SOLUTION TANK & METERING PUMP
METHANOL 55 GAL DRUM
METHANOL FEED PUMP
CONCENTRATED DEFOAMER CHEMICAL
CITY WATER
DEFOAMER SOLUTION TANK & METERING PUMP
LEGEND
NEW
TEMPERATURE CONTROL VALVE
PRESSURE REDUCING VALVE
CENTRIFUGAL PUMP
METERING PUMP W/MANUAL POSITIONER
METERING PUMP W/AUTOMATIC POSITIONER
PRESSURE RELIEF VALVE
GATE VALVE
BALL VALVE
GLOBE VALVE
BUTTERFLY VALVE
N.C. NORMALLY CLOSED
EXISTING
ROTAMETER
LEGEND-INSTRUMENTATION
FIRST LETTER(S) PARAMETER
T TEMPERATURE
DO DISSOLVED OXYGEN
P PRESSURE
PH pH
F FLOW
LAST LETTER(S) FUNCTION
C CONTROLLER
X TRANSMITTER
A ALARM
AL ALARM(LOW)
S SWITCH
I INDICATOR
ARMCO
REVISED
5-10-83
6-7-83
8-15-83
8-29-83
10-4-83
9-10-84
COKE DEPT.
WASTEWATER PILOT TEST
PROCESS SCHEMATIC
SCALE NONE
DATE MAY 9 1983
BY CRM
CHKD TEG
101

FIGURE 5: PILOT TEST SYSTEM PROCESS SCHEMATIC

A soda ash solution feed system was installed to supply the inorganic carbon needed for nitrification. The solution was metered to the mix tank at a rate necessary to maintain the desired residual alkalinity in the MPP effluent.

A defoamer chemical solution tank and metering pump were installed. The defoamer was needed throughout the testing program to help control the severe foaming tendency of the wastewater in the MPP.

DESCRIPTION OF TEST PROGRAM

OBJECTIVES

1. Demonstrate the use of the innovative BMTS for treatment of high-strength coke plant wastewater.

2. Determine the minimum amount of pretreatment required prior to biological treatment with regard to phenol and ammonia.

3. Develop design data and estimate capital and operating costs for two types of potential full-scale biological treatment facilities: high rate (phenol removal only) and low rate (full nitrification).

PHASES

There were three distinct phases of this study. Phase I involved biological treatment of the coke plant wastewater after complete pretreatment. This included use of the full capacity of the existing phenol stripping system, Sulfiban wastewater segregation and separate treatment, the full-scale "free leg" ammonia stills, plus a pilot-scale column for air stripping of fixed ammonia.

Phase II simulated the shutdown of the full-scale phenol stripping system by adding progressively larger quantities of by-product phenol to the influent of the BMTS. The phenol concentration was increased until it approximated the levels which would occur if the phenol plant were eliminated. Operating and design parameters were determined which would minimize the size of the system required for complete phenol removal.

In Phase III, an intensive effort was made to establish and maintain nitrification. Following this, the ammonia concentration in the feed to the BMTS was gradually increased until it reached the level in the current coke plant discharge (ammonia stripped using the full-scale free leg stills only).

DISCUSSION OF PILOT SYSTEM OPERATING DATA

Key operating periods of the pilot study are summarized in the following listing:

- Phase I: 12/6/83 (Day 1) - 1/16/84 (Day 42).
- Phase II: 1/21/84 (Day 47) - 2/8/84 (Day 65).
- Phase IIIA: 2/18/84 (Day 75) - 5/13/84 (Day 160).
- Phase IIIB: 5/15/84 (Day 162) - 6/15/84 (Day 193).
- Nitrification Period 1: 3/28/84 (Day 114) - 4/12/84 (Day 129).
- Nitrification Period 2: 5/26/84 (Day 173) - 6/30/84 (Day 208).

Effluent standards which would likely be imposed on a direct-discharge biological treatment system can be calculated from published guidelines(1) for existing by-product coke plants. The resulting potential BATEA (Best Available Technology Economically Achievable) limits are shown in Table 2. Pilot system operating and treatment performance data, sorted by the above time periods, are provided in Tables 3, 4, and 5. A brief discussion of the key treatment parameters follows Table 2:

TABLE 2: BATEA EFFLUENT STANDARDS - EXISTING SOURCES - BY-PRODUCT COKEMAKING

	1-Day Maximum		30 Consecutive Day Average	
Parameter	lbs/day[a]	mg/l[b]	lbs/day[a]	mg/l[b]
Ammonia-N	508	174	149	51
Total Cyanide	59.6	20	32.8	11
Phenols	0.6	0.21	0.3	0.10
Benzene	0.3	0.10	--	--
Napthalene	0.3	0.10	--	--
Benzo(a)pyrene	0.3	0.10	--	--

a. Based on 3014 TPD, with a 16% increased allowance for wet desulfurization and a 39% increase for indirect ammonia recovery.

b. Assumes coke plant effluent flow of 350,000 gal/day.

PHENOL

As has been seen in many other biological treatment systems treating coke plant wastewaters, the BMTS easily achieved very high removal rates, averaging, depending on the time period, from 96.5-99.98%. For the 196 test days for which phenol removal could be calculated, the median removal rate was 99.96%. Even so, there were 55 days (of 202) which showed effluent phenol concentrations which exceeded the BATEA maximum of 0.21 mg/l, including 11 > 10.0 mg/l. However, in every case these upsets were caused by inadequate full-scale equalization or extreme variations in MPP influent phenol levels due to difficulties alluded to earlier in making supplemental phenol additions.

In general, influent phenols were far more variable than would be anticipated in a properly equalized, new full-scale system. For example, the 3-year history of Armco's Hamilton installation showed a coefficient of variation (CV) of only 46. During the two nitrification periods, when the overall pilot system was at its most stable, effluent phenols averaged only 0.094 and 0.082 mg/l, respectively. During these periods the influent phenol CV was only 60 and 52, compared to 85 during all non-nitrification periods. Only 4 (of 47) effluent values exceeded the BAT maximum. None exceeded 0.85 mg/l.

TOTAL CYANIDE

As can be seen from the test data presented, cyanide should not be a problem parameter for direct discharge limits as existing concentrations are already in compliance. In any case, average removal rates averaged 39% for the entire study. Unlike every other key constituent, effluent values correlated closely with those in the influent (r = 0.91), strongly indicating that the majority of existing cyanide was not amenable to biological degradation and therefore varied with the influent.

TABLE 3: MEAN PERFORMANCE DATA BY OPERATING PHASES

[a]Parameter	Phase I		Phase II		Phase IIIA		Phase IIIB		Phase III All		Total Study	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
HRT, hours	28		25		72		128		88		65	
SRT, days	53		31		98		63		89		77	
F/M (COD)	0.48		0.62		0.15		0.09		0.14		0.23	
F/M (phenol)	0.01		0.07		0.02		0.01		0.02		0.02	
COD/N	2.5		6.8		5.0		3.5		4.5		3.3	
Phenol	56	1.96	271	0.116	403	1.59	397	0.102	400	1.19	322	1.10
[b]NH_3-N	710	684	460	484	571	450	827	245	638	398	636	451
CN	10.9	6.9	0.52	0.32	1.0	0.53	0.91	0.59	0.98	0.55	1.59	0.97
SCN	480	154	508	50	733	95	819	149	787	106	685	128
BOD, 5-day	604	195	342	104	1333	58	1133	51	1277	56	1132	74
COD	1747	820	2427	630	2867	668	2874	1095	2863	787	2638	842
TOC	313	86	461	78	922	98	984	114	936	101	763	98
Oil & Grease	32	5.5	24	5.4	43	4.9	54	3.8	46	4.6	38	5.0
H_2S	37	<1	26	<1	69	<1	56	<1	66	<1	49	<1
TSS	71	81	68	168	128	153	76	85	113	135	94	125
Aeration Basin												
MLTSS	3351		3948		6202		5989		6154		5388	
Growth, lbs/day	3.0		6.2		2.6		5.0		3.2		3.5	
Growth, lbs/lb phenol	1.26		0.39		0.32		1.08		0.45		0.46	
[c]Growth, lbs/lb COD	0.05		0.06		0.06		0.24		0.08		0.07	
SVI, ml/g	83		58		49		57		51		57	
O_2 Uptake (mg/l/hr/g)	7.9		9.3		4.2		6.1		4.6		6.0	
D.O.	3.0		2.5		3.4		3.0		3.3		3.0	
Temperature, °F	78		76		75		83		77		78	
(Number Operating Days Represented)	(42)		(19)		(86)		(32)		(118)		(208)	

a. All values in mg/l unless otherwise indicated.
b. Influent includes NH_3 loading imposed by breakdown of SCN at rate of 0.24 x SCN removed.
c. Per pound of COD removed.

TABLE 4: MEAN PERFORMANCE DATA BY NITRIFICATION PERIODS

[a]Parameter	Nitrification Period 1 Inf.	Nitrification Period 1 Eff.	Nitrification Period 2 Inf.	Nitrification Period 2 Eff.	All Other Inf.	All Other Eff.
HRT, hours	71		105		56	
SRT, days	73		61		81	
F/M (COD)	0.11		0.17		0.26	
F/M (phenol)	0.02		0.02		0.03	
COD/N	3.8		4.3		3.3	
Phenol	358	0.094	428	0.082	293	1.40
[b]NH_3-N	599	153	945	64	597	565
CN	0.81	0.52	0.92	0.70	1.90	1.11
SCN	776	99	842	259	637	113
BOD, 5-day	1248	70	1384	61	1042	78
COD	2282	742	3478	1570	2474	740
TOC	724	76	1052	128	704	94
Oil & Grease	44	6.3	40	4.8	37	4.9
H_2S	65	<1	50	<1	48	<1
TSS	121	142	72	86	96	130
Aeration Basin						
MLTSS	6700		6047		5100	
Growth, lbs/day	3.5		5.2		3.1	
Growth, lbs/lb phenol	0.48		0.70		0.41	
Growth, lbs/lb COD removed	0.11		0.16		0.06	
SVI, ml/g	59		48		59	
02 uptake, mg/l/hr/g	6.6		8.7		5.4	
D.O.	3.1		2.1		3.2	
Temperature, °F	75		86		76	
(Number Operating Days Represented)	(16)		(35)		(157)	

a. All values in mg/l unless otherwise represented.

b. Influent includes NH_3 loading imposed by breakdown of SCN at rate of 0.24 x SCN removed.

TABLE 5: PERCENT REMOVAL RATES BY OPERATING PERIODS

Parameter	Phase I	Phase II	Phase IIIA	Phase IIIB	Phase III all	Nitrification 1	Nitrification 2	All non-nitrification	Entire Study
Phenol	96.5	99.96	99.6	99.97	99.7	99.97	99.98	99.5	99.7
NH_3-N - %	3.7	-5.2	21	70	38	75	93	5.4	29
(mg/l removed)	(26)	(-24)	(121)	(582)	(242)	(446)	(881)	(32)	(187)
CN, total	37	39	47	35	44	36	24	42	39
SCN	68	90	88	82	87	87	69	82	81
BOD, 5-day	68	70	96	96	96	94	96	93	94
COD	53	74	77	62	73	68	55	70	68
TOC	73	83	89	88	89	90	88	87	87
Oil & Grease	83	78	89	93	90	86	88	87	87

AMMONIA NITROGEN

This was considered to be the most important parameter for investigation during this study. Two of the prime objectives of the pilot work were (1) to prove nitrification capabilities of the BMTS and (2) to optimize nitrification rates to determine the feasibility of replacing fixed leg ammonia stills with increased biological ammonia removal.

Nitrification Period 1

Efforts to establish nitrification (Phase III) began on 2/9/84 (Day 66) with the start of the planned transition in pilot plant operating conditions. The hydraulic retention time (HRT) through the BMTS was gradually increased from 24 to 72 hours, and the sludge age (SRT) was developed to 60-90 days. Temperature and pH were controlled within or near optimum ranges (72-86°F and 7.0-7.6)(6).

Ammonia loading and effluent concentrations are graphed in Figure 6 and illustrate both the onset and subsequent failure of nitrification. On March 17 (Day 103), supplemental feed of sodium carbonate was begun to supply an excess of the inorganic carbon and alkalinity necessary for nitrification. This appeared to provide the needed stimulus to the system, as signs of ammonia removal began the same day. By March 28 (Day 114), strong nitrification was in evidence. From March 28 to April 12, ammonia removal performance averaged 75%. About 446 mg/l of ammonia were removed.

Although planned steps to phase down the pilot ammonia stripper had begun, the effort was cut short when a major biological system upset (high pH in basin - up to 9.9) on April 12-13, followed by a 6-hour electrical outage on April 21, resulted in total failure of nitrification. Although the BMTS was stabilized fairly quickly (phenol removals were back to normal by April 17 and were not affected by the power outage), nitrification could not be immediately re-established.

Nitrification Period 2

Ammonia loadings and effluent concentrations are depicted in Figure 7 and again illustrate the onset of nitrification and progress of increasing removal rates through the end of the study.

When nitrification could not be quickly restored, and with allotted project resources dwindling, operational changes were made to assist the system. Additions of large, concentrated doses of purchased nitrifying organisms were made on April 26 (Day 143) and again on May 7 (Day 154), showing little to no effect. On May 15 (Day 162), HRT was increased to 120 hours. The sodium carbonate had previously been added in three dry batches each day. On May 22 (Day 169), a solution makedown and feed system was initiated so that the soda ash could be added continuously to the aeration basin. Finally, on May 23, the addition of freeze-dried, specially-adapted purchased organisms (not nitrifiers) was begun and continued on a daily basis through the remainder of the project. Definite signs of nitrification began on May 24, with very strong ammonia removals in place by about May 26 (Day 173). Although it appeared that these organisms (probably in combination with other operational steps taken) helped restore conditions to allow nitrification, it is not believed that their addition would be a routine necessity in a full-scale facility.

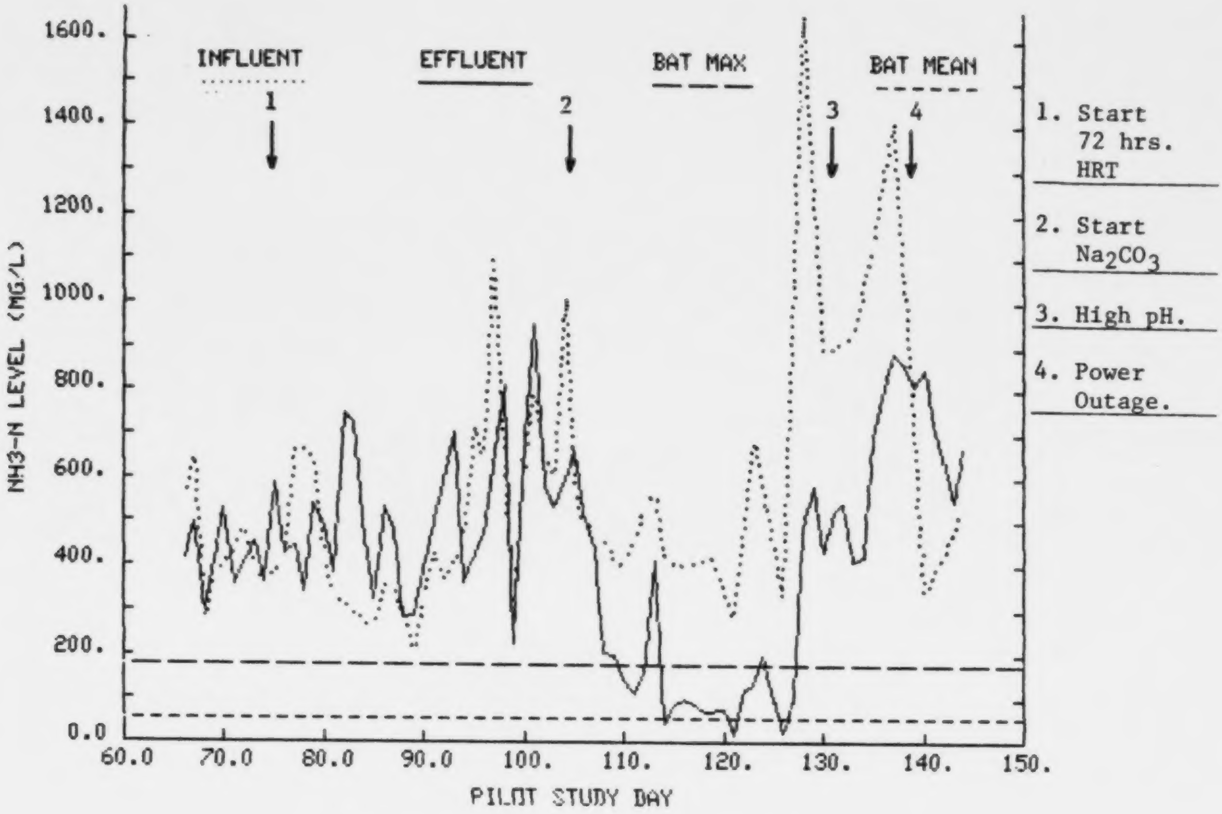


Figure 6. Nitrification Period 1.

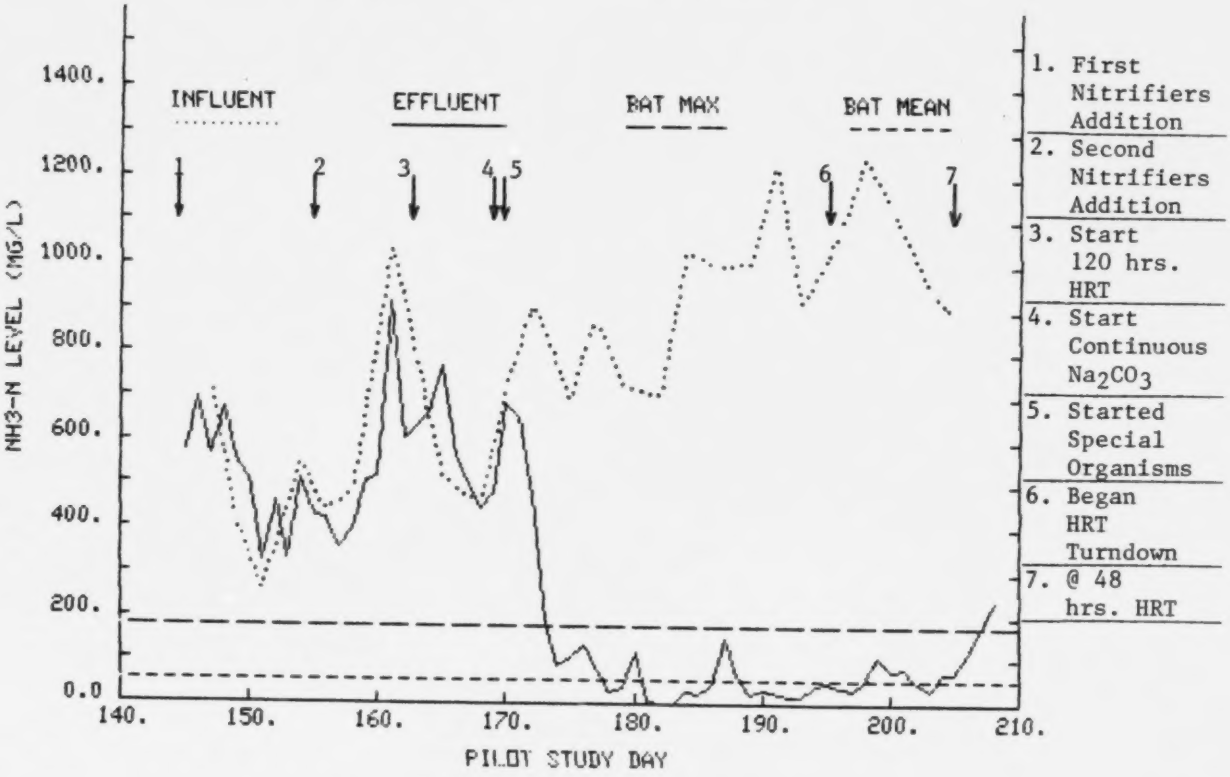


Figure 7. Nitrification Period 2.

As Figure 7 clearly shows, nitrification rates progressed very rapidly. For the period May 26 through June 30 (Day 208), ammonia removal performance averaged 93%, removing a mean of 881 mg/l. Although time and financial constraints prevented an extended running time with high nitrification rates, results over this 35-day period were very encouraging. It is believed to have been demonstrated that it is technically feasible for the BMTS to remove sufficient ammonia to negate the necessity for fixed leg operation. Obviously, it is difficult to predict the long-term system stability based only on this study.

TOTAL SUSPENDED SOLIDS (TSS)

While effluent TSS was frequently higher than desirable, it is believed to have been a problem unique to this application and the physical configuration of the pilot unit. Air requirements for treating this waste, as would be expected, were always high and, at times, extremely high (during high nitrification rate periods, pure oxygen had to be fed into the air system in order to maintain a dissolved oxygen level in the basin). With the pilot system designed for municipal waste and sized for over-road transport, there simply was insufficient space between air headers and the intrachannel clarifier. If in a full-scale system, it would be possible to provide the necessary space.

For possible full-scale design purposes, column settling tests were conducted during June. With the settling characteristics shown in this study (SVIs were consistently <60) and a properly designed BMTS configuration, high-clarity effluent should be obtainable.

PROJECTED FULL-SCALE CAPITAL AND OPERATING COSTS

These projections were based on the conceptual design for a full nitrification plant shown schematically in Figure 8. The design criteria (average/peak) included flow (350,000/450,000 GPD), COD (2500/5000 mg/l), NH_3-N (1100/1500 mg/l), SCN (650/1200 mg/l), and the maintenance of D.O. at 1.0 mg/l under peak conditions. It should be noted that the majority of these components shown in Figure 8 would be needed with any type of biological system.

Projected total installed costs for such a facility in 1984 dollars, including contractor fees, engineering, and 15% contingencies, are estimated at $5,200,000. Annual operating and maintenance expenses are projected to be approximately $922,000-1,302,000, depending on the degree of denitrification established. These costs include a full-time operating crew and treatment plant foreman.

CONCLUSIONS

1. The BMTS is a viable and cost-effective alternative to conventional biological treatment of coke plant wastewater.

2. A full-scale BMTS should be capable of meeting BAT limits for phenol, cyanide, ammonia nitrogen, benzene, naphthalene, and benzo(a)pyrene. Excellent removals were also shown for BOD, COD, TOC, SCN, H_2S, and oil & grease.

3. The technical feasibility of obtaining sufficient biological ammonia removal to negate the need for operation of fixed ammonia stills has been demonstrated on a short-term basis. Additional study or full-scale experience will be necessary to draw strong conclusions on the long-term stability of a system operated in this manner.

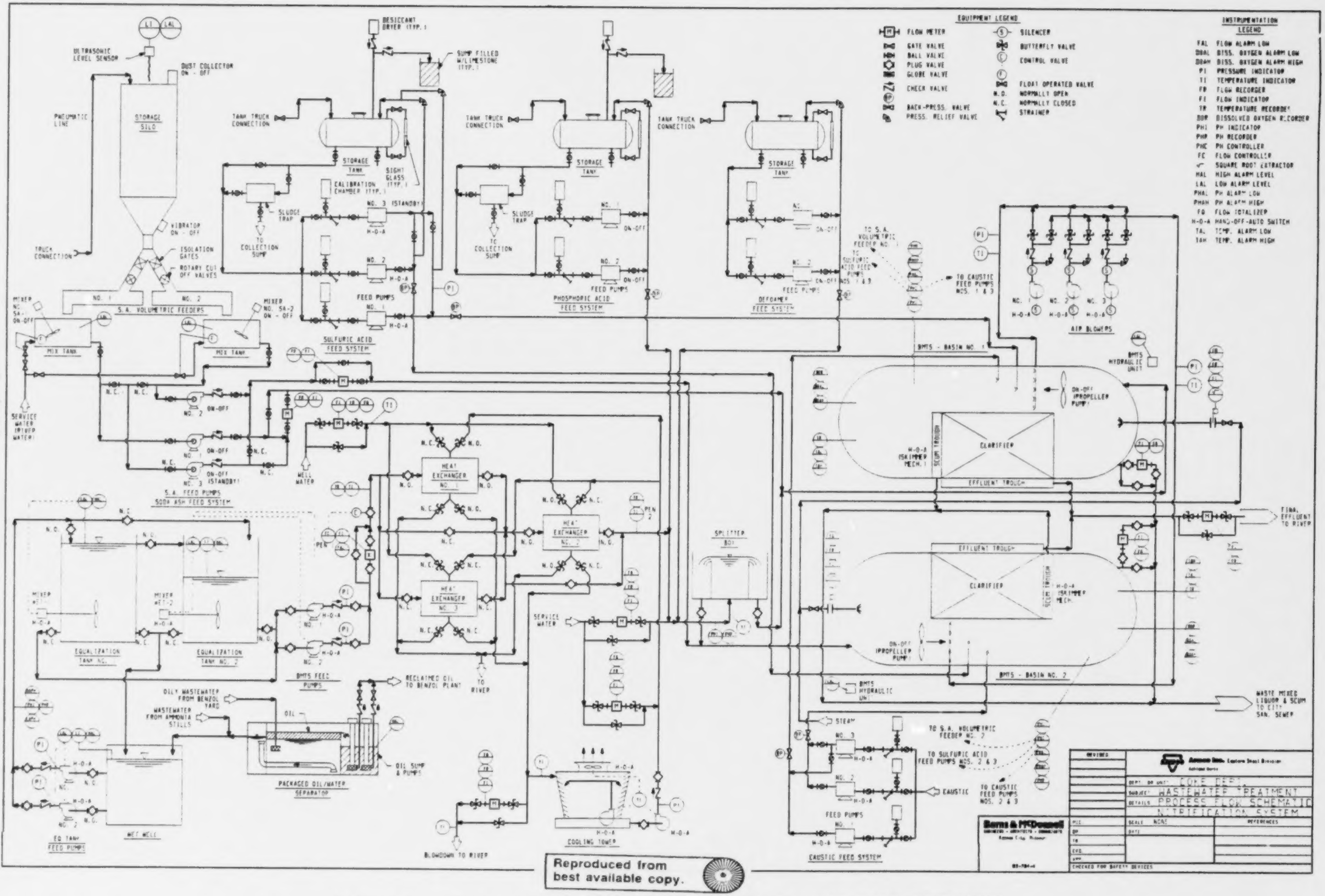

ULTRASONIC LEVEL SENSOR
LI
LAL
DUST COLLECTOR ON - OFF
PNEUMATIC LINE
STORAGE SILO
TRUCK CONNECTION
VIBRATOR ON - OFF
ISOLATION GATES
ROTARY CUT OFF VALVES
NO. 1
NO. 2
S.A. VOLUMETRIC FEEDERS
MIXER NO. 5A-1 ON-OFF
MIXER NO. 5A-2 ON - OFF
MIX TANK
SERVICE WATER (RIVER WATER)
DESICCANT DRYER (TYP.)
SUMP FILLED W/LIMESTONE (TYP.)
TANK TRUCK CONNECTION
STORAGE TANK
SIGHT GLASS (TYP.)
CALIBRATION CHAMBER (TYP.)
NO. 3 (STANDBY)
SLUDGE TRAP
TO COLLECTION SUMP
FEED PUMPS
H-O-A
SULFURIC ACID FEED SYSTEM
PHOSPHORIC ACID FEED SYSTEM
DEFOAMER FEED SYSTEM
ON-OFF
TO S.A. VOLUMETRIC FEEDER NO. 1
TO SULFURIC ACID FEED PUMPS NOS. 1 & 3
TO CAUSTIC FEED PUMPS NOS. 1 & 3
S.A. FEED PUMPS
SODA ASH FEED SYSTEM
WELL WATER
HEAT EXCHANGER NO. 1
HEAT EXCHANGER NO. 2
HEAT EXCHANGER NO. 3
N.O.
N.C.
PEN
EQUALIZATION TANK NO. 1
EQUALIZATION TANK NO. 2
MIXER #T-1
MIXER #T-2
BMTS FEED PUMPS
RECLAIMED OIL TO BENZOL PLANT
TO RIVER
OILY WASTEWATER FROM BENZOL YARD
WASTEWATER FROM AMMONIA STILLS
OIL
OIL SUMP & PUMPS
PACKAGED OIL/WATER SEPARATOR
WET WELL
EQ TANK FEED PUMPS
SERVICE WATER
SPLITTER BOX
COOLING TOWER
BLOWDOWN TO RIVER
AIR BLOWERS
BMTS HYDRAULIC UNIT
BMTS - BASIN NO. 1
BMTS - BASIN NO. 2
ON-OFF (PROPELLER PUMP)
CLARIFIER
SCUM TROUGH
EFFLUENT TROUGH
H-O-A (SKIMMER MECH.)
FINAL EFFLUENT TO RIVER
WASTE MIXED LIQUOR & SCUM TO CITY SAN. SEWER
STEAM
CAUSTIC
TO S.A. VOLUMETRIC FEEDER NO. 2
TO SULFURIC ACID FEED PUMPS NOS. 2 & 3
TO CAUSTIC FEED PUMPS NOS. 2 & 3
CAUSTIC FEED SYSTEM
EQUIPMENT LEGEND
FLOW METER
GATE VALVE
BALL VALVE
PLUG VALVE
GLOBE VALVE
CHECK VALVE
BACK-PRESS. VALVE
PRESS. RELIEF VALVE
SILENCER
BUTTERFLY VALVE
CONTROL VALVE
FLOAT OPERATED VALVE
N.O. NORMALLY OPEN
N.C. NORMALLY CLOSED
STRAINER
INSTRUMENTATION LEGEND
FAL FLOW ALARM LOW
DOAL DISS. OXYGEN ALARM LOW
DOAH DISS. OXYGEN ALARM HIGH
PI PRESSURE INDICATOR
TI TEMPERATURE INDICATOR
FR FLOW RECORDER
FI FLOW INDICATOR
TR TEMPERATURE RECORDER
DOR DISSOLVED OXYGEN RECORDER
PHI PH INDICATOR
PHR PH RECORDER
PHC PH CONTROLLER
FC FLOW CONTROLLER
√ SQUARE ROOT EXTRACTOR
HAL HIGH ALARM LEVEL
LAL LOW ALARM LEVEL
PHAL PH ALARM LOW
PHAH PH ALARM HIGH
FQ FLOW TOTALIZER
H-O-A HAND-OFF-AUTO SWITCH
TAL TEMP. ALARM LOW
TAH TEMP. ALARM HIGH
REVISED
Armco Inc. Eastern Steel Division
DEPT. OR UNIT COKE DEPT.
SUBJECT WASTEWATER TREATMENT
DETAILS PROCESS FLOW SCHEMATIC NITRIFICATION SYSTEM
SCALE NONE
DATE
REFERENCES
Burns & McDonnell
ENGINEERS - ARCHITECTS - CONSULTANTS
Kansas City, Missouri
CHECKED FOR SAFETY DEVICES

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FIGURE 8: FULL-SCALE NITRIFICATION SYSTEM PROCESS FLOW SCHEMATIC

4. Estimated capital costs for a full nitrification BMTS and auxiliary systems total $5,200,000. Projected annual operating costs for the total system are $922,000-1,302,000, depending on the degree of denitrification established.

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DIRECT BIOLOGICAL TREATMENT OF HIGH STRENGTH COKE PLANT WASTEWATERS FOR BAT COMPLIANCE

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Pittsburgh, Pennsylvania 15219

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ABSTRACT

High nitrogen-strength wastewaters such as coke plant wastewaters conventionally require significant and costly pre-processing and treatment for compliance with EPA's stringent BAT Effluent Guidelines. In a joint effort, Environmental Research & Technology, Inc. and United States Steel Corporation have developed an innovative biologically-based process for the treatment of high nitrogen-strength wastewaters which greatly reduces both the complexity and the cost of achieving BAT compliance. ERT/USS's NITE/DENITE^{tm} Process* treats high nitrogen-strength wastewaters without pretreatment (e.g., NH_3 stripping) in a single reactor, single sludge bioreaction system with direct discharge of processed wastewaters at BAT compliance levels. Depending upon site-specific factors, existing biological treatment systems can be retrofitted to utilize the technology. The technical and economic feasibility of the ERT/USS process has been proven over a 4 year period of bench and pilot-scale testing and is now ready for commercial demonstration.

The present paper describes the technology, outlines the four year bench and pilot-scale development program associated with it, and highlights available data on the technology's technical, environmental and economic performance.

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*Trademark of ERT and USS. U.S. patent pending on the process covered by this trademark.

BACKGROUND

In a by-product coke plant, wastewaters are generated at several processing points depending on the nature of the gas cleaning system and by-product recovery operations. Principal wastewater sources are:

- Waste ammonia liquor (flushing liquor),
- Final cooler blowdown,
- Benzol (light oil) plant blowdown.

Other processing operations, if present, will produce such additional wastewaters as gas desulfurization blowdown and ammonium sulfate crystallizer blowdown. Compositional data for these wastewater streams have been reported (1,2,3). Illustrative raw wastewater composition data presented in Table 1 show that combined wastewater streams are highly contaminated with ammonia, cyanide, organics (phenols) and thiocyanate and that these streams require substantial treatment is required to reach the discharge quality specified by the Best Available Technology Economically Attainable (BAT) Effluent Limitations (Table 1).

EPA cites two basic approaches to on-site BAT-level treatment available, i.e., physical/chemical treatment and biological treatment. As is shown in Figure 1A, physical/chemical treatment inherently involves a number of separate treatment operations, each focused on the removal of a specific chemical constituent in the wastewater, viz., solvent extraction for phenol removal, steam strippers for the removal of NH_3, free cyanide, and sulfur, and alkaline chlorination for ammenable cyanide removal. Designed for BAT-level compliance, physical chemical treatment systems are complex and costly to operate (4). As shown in Figure 1B, biological treatment, while subject to some potential for toxic upsets, requires relatively fewer treatment operations, viz., steam strippers for the removal of NH_3, free cyanide and sulfur, bioreactors, sludge clarifiers, and sludge dewatering equipment. However, designed for BAT-level compliance, total treatment costs are also high, due in large measure to the incremental costs associated with achieving consistently high nitrogen removal efficiencies in steam stripping and consistently high biological nitrification of residual nitrogen entering the bioreactor.

The first step in upgrading a coke plant wastewater treatment system to achieve BAT discharge limits traditionally involves either installing a high performance steam stripper or upgrading an existing steam stripper system to achieve reliably high NH_3 removal performance. When employed in conjunction with conventional biological treatment, high performance NH_3 still operation is typically defined as controlling stripping performance to achieve maximum NH_3 concentrations in still bottoms of 50 to 150 mg/l. At these levels, the biological nitrification of approximately 150 to 250 mg/l of NH_3 is required to achieve a BAT compliance discharge limit of 32 mg/l (30 day average). Such performance reflects the traditionally understood limits of nitrification reliably achievable in any biological treatment system.

TABLE 1. ILLUSTRATIVE WASTEWATER COMPOSITIONS AND BAT LIMITS FOR EFFLUENT DISCHARGE

BASIS: USS FAIRLESS WORKS
100 Gallons Raw Wastewater/Ton Coke Produced

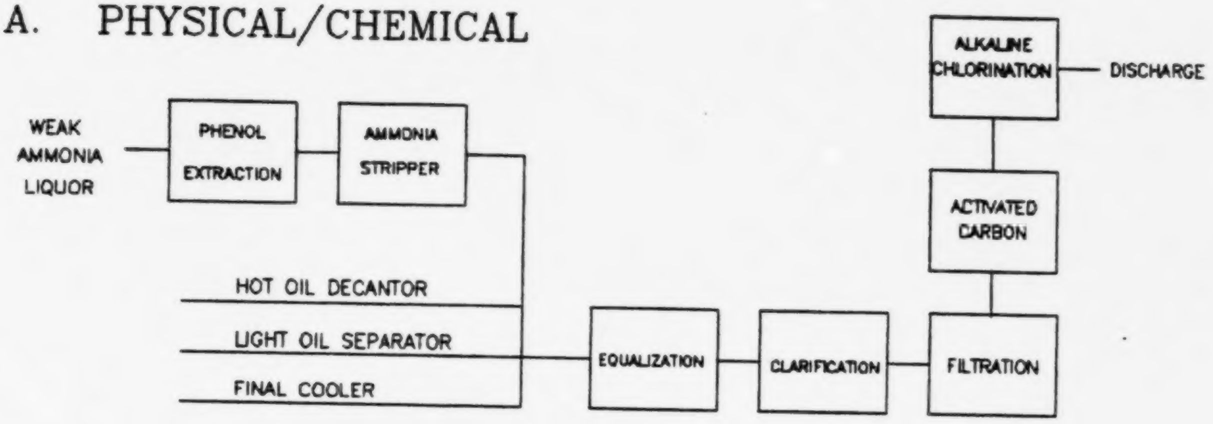
	Wastewater Composition, mg/l		30-Day BAT Limits, mg/l (3)		One Day Maximum, mg/l	
Component	(1) Raw Water	(2) Stripped Water	Raw Water	Stripped Water	Raw Water	Stripped Water
TSS	50	N/A(4)	314	262	607	506
O&G	N/A(4)	N/A(4)	26	22	78	65
Ammonia	1800	100	38	32	130	109
Cyanide, Total	60	N/A(4)	8.4	7	15	13
Phenol	560	470	0.077	0.064	0.153	0.128
COD	4300	3600	N/L(5)	N/L(5)	N/L(5)	N/L(5)
Thiocyanate	560	N/A(4)	N/L(5)	N/L(5)	N/L(5)	N/L(5)
Hydrogen Sulfide	10	N/A(4)	N/L(5)	N/L(5)	N/L(5)	N/L(5)
Benzene	5.4	4.5	N/L(5)	N/L(5)	0.077	0.064
Naphthalene	0.8	0.7	N/L(5)	N/L(5)	0.077	0.064
Benzo(a)Pyrene	0.1	0.1	N/L(5)	N/L(5)	0.077	0.064

Footnotes:

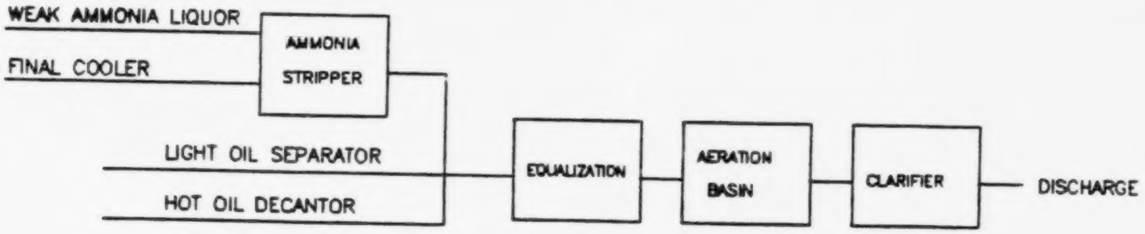
(1) Raw wastewater composition is based on data collected by ERT at U.S. Steel Fairless Works bi-weekly from June, 1983 to June, 1984.
(2) Stripped water composition is based on two-thirds of the raw water processed by the still, and an additional 20 gallons of steam condensate added to the flow for each ton of coke produced. This makes the total flow for a stripped water equal to 120 gallons per ton of coke processed.
(3) Daily averages for 30 consecutive days.
(4) Not Available.
(5) No Regulatory Limit.

FIGURE 1

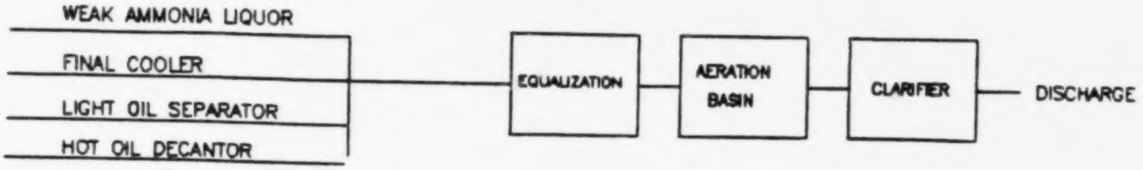
BLOCK FLOWSHEETS FOR WASTEWATER TREATMENT
OF COKE PLANT WASTEWATERS TO BAT COMPLIANCE LEVELS


A. PHYSICAL/CHEMICAL

WEAK AMMONIA LIQUOR
PHENOL EXTRACTION
AMMONIA STRIPPER
HOT OIL DECANTOR
LIGHT OIL SEPARATOR
FINAL COOLER
EQUALIZATION
CLARIFICATION
FILTRATION
ACTIVATED CARBON
ALKALINE CHLORINATION
DISCHARGE


B. CONVENTIONAL BIOTREATMENT

WEAK AMMONIA LIQUOR
FINAL COOLER
AMMONIA STRIPPER
LIGHT OIL SEPARATOR
HOT OIL DECANTOR
EQUALIZATION
AERATION BASIN
CLARIFIER
DISCHARGE


C. USS/ERT NITE/DENITE TECHNOLOGY

WEAK AMMONIA LIQUOR
FINAL COOLER
LIGHT OIL SEPARATOR
HOT OIL DECANTOR
EQUALIZATION
AERATION BASIN
CLARIFIER
DISCHARGE

NITE/DENITE^{tm} TREATMENT TECHNOLOGY

Basic components of the NITE/DENITE^{tm} process are illustrated in Figure 1C. With the exception of the reduced role/elimination of the steam stripper, the basic components and sizes of a NITE/DENITE^{tm} system can be comparable to those of a conventional biological treatment system.

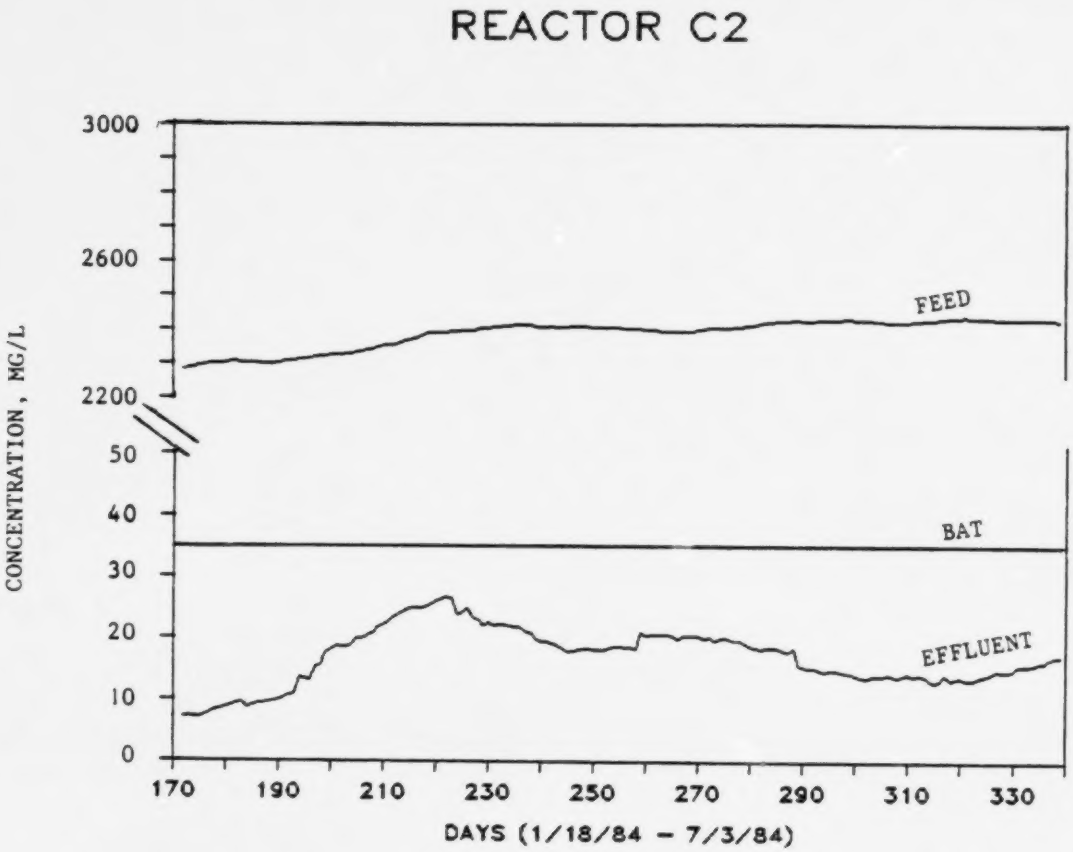
The heart of the NITE/DENITE^{tm} process is innovation to achieve and sustain substantially complete nitrification of all wastewater nitrogen fed to a biological reactor independent of feed concentration. ERT/USS have demonstrated sustained biological nitrification of wastewaters containing widely varying levels of NH_3 and other forms of reduced nitrogen (organic nitrogen, free cyanide, thiocyanate) to discharge levels consistently below BAT limits of 32 to 38 mg/l. Figure 2 illustrates a 197 day segment of operating data from one of ERT/USS's test program reactors operated on a coke plant feedwater containing 2200 mg/l of NH_3 and a total of 2500 mg/l of reduced nitrogen (TKN). The ramification of Nite/Denite's^{tm} unique nitrification capability is that the costly pretreatment step of steam stripping for NH_3 removal can be reduced or eliminated, the decision being governed strictly by overall treatment system economics.

To achieve the principal economic goal of minimizing capital and operating costs, NITE/DENITE^{tm} accomplishes controlled levels of denitrification of the products of nitrification. In contrast to conventional multi-staged nitrification and denitrification processes (5, 6, 7, 8), NITE/DENITE^{tm} accomplishes its denitrification work simultaneous with its nitrification work in the same reactor utilizing the same sludge. The result is a single stage, single sludge bioreactor which simultaneously performs nitrification and denitrification reactions on high nitrogen-strength wastewater.

The bioreactor in the NITE/DENITE^{tm} process must be equipped with an alkalinity supply/pH control system, and with an aeration system capable of supplying air in excess of quantities required of conventional bioplants. Alkali is required for neutralization because the nitrification reaction is a producer of acid (two units of acid are produced for each unit of nitrogen oxidized). The total quantity of alkali required depends upon the degree of denitrification achieved, since denitrification is a generator of alkali (one unit per unit of nitrogen reduced). Additional quanties of oxygen are required to oxidize the constituents entering the biosystem which in conventional system are removed by the ammonia still. The total oxygen required depend upon the degree of denitrification achieved, since denitrification transfers nitrogen-bound oxygen to the oxidation of organics, thereby reducing total system oxygen demand.

The first economic advantage of the NITE/DENITE^{tm} process derives from the elimination of all operating and any potential capital costs otherwise associated with use of the ammonia still. This goal is accomplished by applying the nitrification portion of the NITE/DENITE^{tm} technology. The second economic advantage of the NITE/DENITE^{tm} process derives from the

FIGURE 2



RUNNING 30-DAY AVERAGES

FEED NH_3

EFFLUENT NH_3

Note: Average ammonia discharge for this 197 day period was 16.5 mg/l. The standard deviation was 12.2 mg/l; therefore, statistically 67% of the effluent ammonia readings will be less than 28.7 mg/l; 95% will be less than 40.9 mg/l; and 98% will be less than 53.1 mg/l substantial reductions in alkali and power costs required to maintain effective biosystem operation. This goal is accomplished by operating the denitrification portion of the technology.

Another economic feature of the NITE/DENITE^{tm} process is a relatively low operating level of dissolved oxygen. At low oxygen levels, oxygen transfer efficiencies are increased, thereby greatly reducing the cost of aeration. This feature may permit the use of existing aeration systems for operation on higher oxygen demand wastewaters.

BASIC MODES OF NITE/DENITE^{tm} SYSTEM OPERATION

The NITE/DENITE^{tm} system is flexible enough to adjust to a wide range of operating circumstances; however, for discussion purposes, it is convenient to talk in terms of three basic modes of operation for treatment of such wastewaters as coke plant wastewater:

- Mode 1: Substantially complete nitrification with partial denitrification of full strength wastewater, i.e., no pretreatment.
- Mode 2: Substantially complete nitrification and denitrification of partially pretreated wastewater, e.g., free leg steam stripping to remove free ammonia.
- Mode 3: Substantially complete nitrification and denitrification of full strength wastewater, i.e., no pretreatment.

The basic configuration of the overall treatment system is essentially the same for each of the above modes of operation. The COD and N composition of the wastewater, degree of pretreatment, the sizing of biotreatment plant equipment and plant operating conditions combine to distinguish individual modes of NITE/DENITE^{tm} process operation and performance. The availability of dissolved organics in the wastewater, the cost of alkali for pH control, and the relative costs for addition of supplemental organic COD versus mild steam stripping for establishment of feed COD to N ratios largely control the choice of most economic operating mode.

Typical raw coke plant wastewater organic COD to nitrogen ratios of 1.1:1 to 1.8:1 permit the operation of the NITE/DENITE^{tm} process in Mode 1, i.e., substantially complete nitrification (i.e., 95 to 99+%) and nominally 25 to 50% denitrification of full strength wastewater. Adjustment of COD to N ratios to atleast 3 to 1 are necessary for complete denitrification. Where economically justified this adjustment can be made either or by removing a portion of the feed nitrogen, typically through partial (free leg) steam stripping (Mode 2 operation), or by adding COD to the wastewater (Mode 3).

NITE/DENITE^{tm} DEVELOPMENT PROGRAM

Development work on the NITE/DENITE^{tm} process has been carried out jointly by ERT and USS over the period 1980 through 1984. Work has involved extensive testing on 17 liter laboratory-scale bioreactors and the field construction and one year operation of a 2000 gallon pilot plant at USS's Fairless Works in Philadelphia. The pilot test phase of the development program was conducted under an Innovative Technology Extension granted to USS by the Environmental Protection Agency.

BENCHSCALE TEST PROGRAM

To date, a total of 6000 reactor-days of benchscale laboratory testing and development have been conducted on 32 separate reactors. The longest continuous benchscale reactor runs have been 580 and 340 days. Typical reactor run times have been atleast 200 days (15 of 32 reactors have run over 200 consecutive days). All testing has been performed on real coke plant wastewater collected at various times from 3 different coke plants. In the majority of cases, testing has been performed on undiluted flushing liquor taken directly from coke plant tar decanters. A summary of the wide range of operating variables examined at the bench reactors is as follows:

Feed Conditions	TKN Level - 120 to 9000 ppm NH_3 Level - 100 to 8000 ppm COD Level - 200 to 6000 ppm COD/N Ratio - 50 to 1.0
Reactor Conditions	Temperature - 10 to 35°C pH - 5.5 to 8.5 Dissolved Oxygen - 0 to 4 ppm Hydraulic Residence Time - 1 to 34 days Food to Microorganism Ratio - 0.02 to 0.3 Mixed Liquor Solids Loadings - 2,000 to 20,000 ppm

PILOTSCALE TEST PROGRAM

A total of 368 days of pilotscale reactor operation were accumulated in a field test of the NITE/DENITE^{tm} process conducted at USS's Fairless Works coke plant from June 1983 through June 1984. All relevant raw wastewater streams in the Fairless Works coke plant were manifolded together and fed to a pair of 1000 gallon equalization basins where blended raw wastewater was fed without dilution at a controlled rate to a 2000 gallon bioreactor (feed composition cited in Table 1). The bioreactor was equipped with a 2 hp aerator/mixer and systems for the controlled addition of alkali (Na_2CO_3) and acid (HCl) for pH management. Dissolved oxygen probes, pH sensors and electronic controllers were employed to regulate the aerator/mixer and the alkali/acid addition systems. Sludge discharge from the bioreactor was separated in a clarifier from which sludge was recycled to the bioreactor and treated wastewater was sampled for analysis and discharged.

OPERATION OF SYSTEMS WITH COMPLETE NITRIFICATON (MODE 1)

The first goal of the development program was to demonstrate the ability to totally bypass ammonia stills while attaining substantially complete nitrification and oxidation of other waste consitituents (e.g., cyanide, thiocyanate, organics) to levels required for compliance with BAT discharge limits (Table 1). Data provided in Table 2 illustrates BAT effluent testing results of several bench reactors and the pilot plant. Nitrification performance in all of the reactors is consistently high and effluent NH_3 is consistently below BAT limits. Phenol removal is consistantly high, with fluctuations in effluent loading slightly above and below BAT limits. In all cases higher effluent phenol levels (typically above 0.1 ppm) can be traced to short term bioreactor stress related to operator induced changes in reactor operating conditions. Each time reactor conditions changed significantly from one setting to another (e.g., operating pH, dissolved oxygen level, feed load), phenol levels in the effluent rose temporarily until the system could readjust to the new operating conditions. When allowed to equilibrate, high phenol removal was re-established within several days. Where successive changes in operating conditions were performed, high phenol removal was re-established only after the last shift in operating conditions was permitted to equilibrate. This latter stituation explains the somewhat higher average phenol levels experienced during the pilot plant compliance period. Small, but important changes in operating conditions were made through-out most of the compliance period, largely directed to increasing the denitrificaton performance of the reactor. These changes had no adverse effect on ammonia discharge levels; and their temporary effects on phenol levels were only appreciated in hindsight.

The denitrification levels achieved at the pilot plant during the compliance test period were approximately 25%. Denitrification levels achieved in the bench reactors during the periods shown in Table 2 varied from 15 to 50%.

OPERATION OF SYSTEMS WITH PARTIAL STRIPPER (MODE 2)

A number of reactors have been operated on wastewater compositions typical of partially stripped coke plant waters. Table 3 provides a brief summary of selected results of these operations. The only compliance data tracked during these operating periods were effluent ammonia concentration and effluent total suspended solids.

OPERATION OF SYSTEM WITH COMPLETE NITRIFICATION AND DENITRIFICATION OF UNSTRIPPED WATERS (MODE 3)

Coke plant wastewaters typically have COD to N ratios substantially below the 3 to 1 required for substantially complete denitrification. A number of reactor studies have been conducted (both bench and one pilot

TABLE 2

SUMMARY OF REACTOR COMPLIANCE DATA FOR BAT PARAMETERS

(Mode 1 Operation)

Reactor	Total Operating Days	Influent NH_3 mg/l	Average Effluent Concentration, mg/l				
			NH_3	Phenol	Total CN	TSS	Oil Grease
BAT Compliance		-	32	0.077	8.4	314	26
Pilot Plant	40	1655(40	7.7(40)	0.0853(40)	-	90(40)	6.94(31)
A2	126	1748(126)	9.5(126)	0.0469(34)	2.57(13)	117(54)	-
A4	126	1269(126)	13.9(126)	0.0448(18)	2.04(8)	36(54)	-
B2	112	2382(111)	19.4(112)	0.1198(35)	2.87(14)	101(48)	-
C2	126	2391(126)	18.7(126)	0.0540(29)	2.44(10)	141(54)	-
O2	106	1179(106)	16.4(106)	0.0471(16)	1.52(8)	61(45)	-
O3	62	1307(62)	19.8(62)	0.0498(10)	0.89(9)	62(27)	-
AVERAGE		1748(698)	15.5(698)	0.0795(182)	2.17(62)	89(322)	6.94(31)

Footnote:

The numbers in parenthesis represent the number of data points for each reactor parameter.

TABLE 3

SELECTED OPERATING RESULTS FOR PARTIALLY STRIPPED WASTEWATER REACTORS (MODE 2 OPERATION)

Reactor		Days Operated	Feed TKN Conc., mg/l	HRT	% Feed On Line	% Nite	% Denite	Average Effluent NH_3, mg/l
Pilot Plant								
	o Period A	80	584	5	93.49	96.48	86.87	19.5
	o Period B	29	1424	5	99.14	95.05	89.13	57.1(2)
A1		61	835	4.5	94.43	96.73	92.17	15.9
A3	o Period A	63	653	5	97.97	95.77	96.18	12.9
	o Period B	49	1087	4	98.43	97.31	72.98	16.9
B1		154	840	3.5	92.66	97.18	83.65	14.3
C1		108	1016	5	N/A(1)	97.86	72.42	18.1
C2		72	987	4	79.60	96.73	91.07	22.5
H3	o Period A	94	984	4	N/A(1)	98.47	64.74	10.7
	o Period B	28	1156	4	N/A(1)	96.45	81.48	32.4
H4		122	1315	3.8	90.85	98.56	84.34	19.1
H6		106	908	3.5	96.31	96.43	93.13	18.4

(1) Data on percent feed on the time not recorded.

(2) Effluent NH_3 level from pilot plant during this period was high due to a rapid increase in feed load (4% daily increase for 19 consecutive days).

scale) in which COD to N ratios were set at 3 to 1 and greater by addition of sodium phenolate. However, technically this work was performed at feed water NH_3 levels somewhat below those cited in Table 1 as typical of full strength wastewater (1000 to 1400 mg/l TKN vs 2000 mg/l TKN) and so the results of this work have been reported in Table 3 under Mode 2 operation (in effect, reduced NH_3 loads equivalent to partial stripping). As the last step in the development program, experiments are presently in progress to confirm that full strength raw wastewaters at 2000 mg/l TKN, when spiked with a carbon source to bring them to a COD to N ratio of 3 are also readily processed to complete denitrification. Somewhat counterintuitively, the economic incentive for COD spiking is substantial: per unit of denitrification, methanol addition at 50 cents a gallon is 60 percent less costly than the Na_2CO_3 that would be needed for neutralization in the absence of a unit of denitrification.

NITE/DENITE^{tm} PROCESS ECONOMICS

Battery limits capital and operating cost estimates are presented in Table 4 for comparative analysis of 5 alternative coke plant BAT treatment scenarios:

(1) Conventional biological treatment in conjunction with an upgraded existing NH_3 still.

(2) Conventional biological treatment in conjunction with the installation of a new CYAM^{tm} super NH_3 still.*

(3) Mode 1 application of NITE/DENITE^{tm} processing -- partial denitrification of full strength liquor.

(4) Mode 2 application of NITE/DENITE^{tm} processing -- complete denitrification of partially stripped wastewater (existing still available, capable of free leg stripping).

(5) Mode 3 application of NITE/DENITE^{TM} processing -- complete denitrification of full strength wastewater.

In developing cost data, the wastewater compositions outlined earlier in Table 1 have been used. Similarly, in determining the sizes of process equipment and system operating costs, flowrates of water, chemicals, and utilities for a typical 3000 ton/day coke plant have been used. Capital costs are referenced to the 2nd quarter, 1984.

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*CYAM is a licensed USS technology for the high performance steam stripping of coke plant wastewater.

TABLE 4. ESTIMATED BATTERY LIMITS CAPITAL AND OPERATING COSTS FOR CONVENTIONAL VS NITE/DENITE^{tm} TREATMENT OF COKE PLANT WASTEWATER

Basis: (1) 3000 ton/day coke plant; 210 gal/min raw wastewater flow.
(2) Wastewater compositions reported in Table 1.
(3) Unit operations and flows as reported in Figures 1B and 1C.

Item	Conventional Biosystem		Nite/Denite^{tm} Process System				
	Upgraded Existing Still	CYAM^{TM} NH3 Still	Mode 1 (1)		Mode 2 (2)	Mode 3 (3)	
Battery Limits							
Capital Cost, $	$4,900,000	$6,900,000	$4,500,000		3,900,000	$4,500,000	
Operating Cost, $/yr (4)			25% DN	50%DN		Natural COD/N	COD Supplement
o Amortization of capital	$640,000	$910,000	$580,000	580,000	$500,000	$580,000	580,000
o Electricity	150,000	150,000	280,000	260,000	190,000	210,000	210,000
o Steam	1,560,000	940,000	--	--	620,000	--	--
o Lime	150,000	150,000	--	--	--	--	--
o Sulfuric Acid	200,000	200,000	--	--	100,000	--	--
o Ammonium Sulfate (credit)	(160,000)	(160,000)	--	--	(80,000)	--	--
o Still Additives	40,000	40,000	--	--	20,000	--	--
o Sludge Conditioning and Disposal	100,000	100,000	20,000	20,000	20,000	20,000	20,000
o Still Operating and Maintenance Manpower	160,000	160,000	--	--	160,000	--	--
o Soda Ash	--	--	830,000	690,000	70,000	330,000	330,000
o COD Supplement	--	--	--		--	--	140,000
TOTAL ANNUAL SYSTEM COSTS	$2,840,000	$2,490,000	$1,710,000	1,550,000	$1,600,000	$1,140,000	1,280,000

Footnotes:

(1) Mode 1: 25% and 50% denitrification of full strength wastewater; i.e., no pretreatment
(2) Mode 2: Complete denitrification of partially pretreated wastewater, either due to natural COD/N of over 3.0, or by supplemental COD to raise COD/N above 3.0.
(3) Mode 3: Complete denitrification of full strength wastewater.
(4) Basis:

- o Amortization at 10% interest over 15 years
- o Electricity at $0.055/kwhr
- o Steam at $8.47/1000 lbs delivered ($5/MMBTU fuel)
- o Lime at $60/ton
- o NH_3 still labor and maintenance at $450/day
- o Soda ash at $160/ton
- o Capital costs are battery limit costs based on 2nd quartered, 1984 dollars.
- o COD supplement: Methanol @ $0.50/gal.

IMPLICATION FOR COKE PLANT OPERATORS

Coke plant operators with existing biological treatment plants have the greatest potential for immediate leveraged cost savings with NITE/DENITE^{tm}. If their bioplant is retrofittable, the payout time on retrofitting costs for an existing bioplant can be as little as 6 months to a year. Exclusive of capital costs recovery for retrofitting, savings of \$1.1 million per year are possible in a nominal 3000 ton/day coke plant by eliminating the operation of just the fixed leg portion of the NH_3 still (Table 4: existing still operating costs less Mode 2 operating costs). Shutdown of the remainder of NH_3 still operations can save an additional \$400,000 to \$540,000 per year (Table 4: Mode 3 with either naturally occurring or methanol-supplemented raw wastewater).

At a minimum where coke plant operators have old existing NH_3 stills, they can avoid refurbishment of those stills and shut down the fixed leg portion of their operation by building a NITE/DENITE^{tm} biosystem (Mode 2 operation). Savings associated with this mode of operation (Table 4: about \$1.25 million/year for a 3000 ton/day coke plant) represent more than twice the annual amortization cost of the capital required to build the NITE/DENITE^{tm} system (Table 4: about \$600,000 per year). Complete shutdown of the still can yield an additional \$400,000 to \$540,000 per year in savings (Table 4: Mode 3 operation).

Coke plant operators presently without either NH_3 still pretreatment or primary wastewater treatment equipment can save approximately \$2.5 million in capital by cancelling pretreatment system investments and installing NITE/DENITE^{tm} (Table 4: Mode 3 relative to CYAM^{tm} new still). Annual operating savings in this case can exceed \$1.2 million.

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USE OF THE MODIFIED HDS PROCESS TO TREAT BLAST FURNACE BLOWDOWN

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ABSTRACT

The Modified High Density Sludge (Modified HDS) process is a technique for treating blast furnace blowdown that contains high levels of zinc and cyanide. In this process, ferrous iron is added to blast furnace blowdown to break the zinc-cyanide complex and the HDS process is used to precipitate zinc as zinc hydroxide and cyanide as a ferrocyanide.

Results of our laboratory work show that for blast furnace blowdown containing up to 70 mg/l zinc and up to 30 mg/l cyanide, the addition of soluble ferrous iron will reduce soluble zinc concentrations to less than 0.3 mg/l and total cyanide concentrations to less than 2.0 mg/l. Sludge densities of 10 - 25% solids in the thickener underflow can be achieved, minimizing disposal costs.

INTRODUCTION

Bethlehem Steel has evaluated various treatment technologies to meet the effluent limitation guidelines for the discharge of blast furnace blowdown. Several of these studies have been aimed at first removing heavy metals with treatment in existing biological treatment facilities to remove ammonia and phenol. In these studies, we have found that in blast furnace wastewaters containing high concentrations of zinc (30 - 70 mg/l) and cyanide (5 - 30 mg/l), a soluble zinc-cyanide complex is present and prevents the reduction of soluble zinc to acceptable levels in conventional hydroxide precipitation processes. Figure 1 shows a comparison of zinc solubilities for a solution containing no cyanide and a solution containing 25 mg/l cyanide.

While alkaline chlorination will eliminate the zinc-cyanide complex problem by destroying the cyanide and allowing the zinc to precipitate, this approach is unfavorable because the potential formation of trihalomethanes as discussed by Hall et al (1) and because of its high cost. Consequently, a treatment process that could economically reduce heavy metal and cyanide concentration combined with subsequent treatment to remove ammonia and phenol could provide a cost-effective alternative to alkaline chlorination for the treatment of blast furnace blowdown. To accomplish this, Bethlehem has developed the Modified High Density Sludge (Modified HDS) process.

DESCRIPTION OF THE MODIFIED HIGH DENSITY SLUDGE PROCESS

The Modified HDS process combines a mechanism for the removal of cyanide and complexed metals with the advantages of dense sludge production that come from the Bethlehem-developed High Density Sludge process.

HIGH DENSITY SLUDGE PROCESS

The High Density Sludge (HDS) process is an improved neutralization process for the treatment of acidic, metal-bearing wastewaters. As described by Herman (2), the HDS process can be used to treat metal-bearing wastewater and produce a sludge containing up to 50% solids. A block diagram comparison of the HDS and conventional neutralization processes is presented in Figure 2. The key differences between HDS and conventional neutralization treatment are that 1) a controlled volume of the settled sludge is recycled back trough the neutralization process and 2) the recycled sludge is mixed with the alkaline agent in a reactor prior to the neutralization and solids separation steps.

The Modified High Density Sludge Process

In the Modified HDS process (shown in Figure 3), ferrous iron is used to break the zinc cyanide complexes in the blast furnace blowdown prior to HDS treatment to produce 1) an effluent that is low in both dissolved zinc and cyanide and 2) a sludge that is up to 30% solids. In this process blast furnace blowdown is combined with a solution of soluble ferrous iron in Reactor C where the zinc cyanide complex is broken. Effluent from Reactor C enters Reactor B, where the zinc, iron, and newly formed iron-cyanide are precipitated. The solution from Reactor B enters a thickener where the precipitated solids are removed. Clarified effluent overflows the thickener and is discharged. A portion of the sludge is recycled to Reactor A where it mixes with lime before overflowing into Reactor B to precipitate solids and promote the formation of high density sludge.

LABORATORY TEST PROCEDURES

A bench scale Modified HDS system, complete with chemical feed system, pH control, sludge thickening and sludge recycling, was used to conduct this test program. Aqueous ferrous sulfate provided the ferrous iron source and aqueous calcium hydroxide was used to adjust pH.

The feed water for this system was blowdown wastewater from the gas cleaning system at our Bethlehem plant blast furnace. During our test program, the concentrations of EPA-regulated pollutants in this water were well below the concentrations expected during normal operation because of low operating levels and the shutdown of our sinter plant. Consequently, cyanide, zinc, lead, phenol, and ammonia were added to increase their concentrations to levels that approximated normal operating conditions. Table 1 lists both the concentration of the blowdown feed water to the experimental system and the BAT concentrations for the respective constituents.

For each test, samples of the blast furnace water and of the effluents from Reactor B, Reactor C, and the thickener were analyzed for zinc, iron, and cyanide. Inlet cyanide concentration was maintained between 10 and 15 mg/l. Inlet zinc concentration was approximately 50 mg/l. The concentration of ferrous iron added to the wastewater was varied to determine its effect on zinc and cyanide removal.

RESULTS AND DISCUSSION

The results of testwork conducted between January and July 1983 are shown in Figures 4 & 5. From this work, we have developed the following observations.

LABORATORY TESTS OF MODIFIED HDS SYSTEM

Effect of Iron Addition on Zinc and Cyanide Removal

The combination of soluble zinc and free cyanide in the blast furnace blowdown results in the formation of a zinc-cyanide complex which is not removed from solution by traditional pH adjustment. However, because of its stronger affinity for cyanide, ferrous iron breaks the zinc-cyanide complex. As the pH is increased, both the the zinc ions and the ferrocyanide ions precipitate from solution.

Figure 4 shows the effluent concentration of free cyanide (cyanide which is available to complex with zinc) as a function of ferrous iron addition when solutions of blast furnace water containing up to 30 mg/l cyanide and up to 70 mg/l zinc are treated in the modified HDS system. At a concentration of between 300 and 350 mg/l ferrous iron, the free cyanide concentration is reduced to between 1.0 and 1.5 mg/l.

As the amount of cyanide in the treated blast furnace blowdown is reduced, the concentration of soluble zinc also decreases due to the destruction of the zinc-cyanide complex and subsequent precipitation of zinc. Figure 5 shows that when free cyanide is reduced to approximately 1.5 mg/l, soluble zinc concentrations can be reduced to approximately 0.3 mg/l.

Effect of Inlet Cyanide on Cyanide Removal

The concentration of free cyanide in the treated blast furnace blowdown determines the amount of zinc that will be complexed and remain in solution. Consequently, the relationship between iron addition and cyanide removal was examined for influent cyanide concentrations ranging from 6 to 30 mg/l. Figure 6 shows that the cyanide effluent curves for all inlet cyanide concentrations exhibit the same general trend, steadily decreasing as iron addition increases to 300 mg/l and flattening out at iron concentrations above 300 mg/l.

Total Cyanide Effluent from the Modified HDS System

In addition to soluble free cyanide, the treated effluent will contain between 0.25 and 0.50 mg/l of soluble cyanide as ferrocyanide and less than 1.0 mg/l of cyanide in the suspended solids. While the soluble ferrocyanides and suspended cyanide do not affect zinc precipitation, they do increase the total cyanide in the effluent. However, total cyanide effluent concentrations will be less than 3.0 mg/l with iron addition of 300 mg/l.

Total Zinc Effluent from the Modified HDS System

Although this modified HDS system will reduce soluble zinc concentration in blast furnace blowdown containing cyanide to 0.3 mg/l or less, it may be difficult for this system to meet a limit of 0.45 mg/l total zinc because of suspended solids in the effluent. Analysis of total suspended solids (TSS) in the Modified HDS effluent from tests using approximately 300 mg/l iron and 50 mg/l zinc showed that zinc solids were 5% of TSS. To meet a 0.45 mg/l limit for total zinc, effluent TSS levels would have to be reduced to between 3.0 and 5.0 mg/l.

These high levels of suspended zinc are not caused by the Modified HDS process but, rather, are the result of high levels of zinc in the blast furnace blowdown due to furnace burden and operation. Similar problems with excessive zinc were encountered during laboratory evaluation of alkaline chlorination systems. When precipitated, this zinc forms an excessively high percentage of the resultant suspended solids and cannot be reduced to EPA-recommended levels using recommended clarification equipment. However, this problem is somewhat lessened with the Modified HDS process because the iron helps partition more zinc to the settled solids.

Effect of pH on Zinc Solubility and Sludge Density

Control of pH in Reactors B and C is important to the removal of both zinc and cyanide from the blast furnace water. The pH in Reactor C should be kept below 7 to keep all of the ferrous iron in solution. At a pH above 7, the ferrous iron will start to precipitate out of solution. While soluble free and complex cyanides will form ferrocyanides at this pH, cyanides that are present as solids will not. When the pH is adjusted for zinc removal this cyanide will dissolve and form soluble complexes with the zinc if the ferrous ion has already precipitated in Reactor C.

The HDS process allows for effective precipitation of metals and maximum sludge density at pH levels below that of conventional neutralization. Consequently, the pH in Reactor B should be between 9.0 and 9.5 to achieve maximum zinc precipitation without sacrificing sludge density. At a pH below 9.0 zinc removal will be inadequate and at a pH of 9.5 or higher, the sludge density decreases significantly (See Table 2).

REFERENCES

1. Hall, S. A., et al, "Pilot Evaluation of Alkaline Chlorination Alternatives for Blast Furnace Blowdown Treatment", Presented at the EPA/AISI Symposium on Iron and Steel Pollution Abatement Technology for 1981, Chicago, OH, October 1981.

2. Herman, S. T., "The High Density Sludge Process: An Improved Technology for Hydroxide Precipitation of Heavy Metals", Presented at the EPA/AISI Symposium on Iron and Steel Pollution Abatement Technology for 1983, Chicago, OH, October 1983.

The work described in this paper was not funded by the U. S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

TABLE 1. COMPARISON OF BLAST FURNACE BLOWDOWN WITH BAT LIMIT

Parameter	Blowdown	BAT limit*
Zinc	30-70 mg/l	0.45 mg/l
Lead	1-2 mg/l	0.3 mg/l
Ammonia**	125 mg/l	10.0 mg/l
Phenol**	1-10 mg/l	0.1 mg/l
Cyanide	10-20 mg/l	3.0 mg/l

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* Based on a design flow rate of 70 gallons per ton
** Phenol and ammonia are not removed by the Modified HDS process

TABLE 2. EFFECT OF pH ON ZINC SOLUBILITY AND HDS SLUDGE DENSITY

5/12/83 - 7/19/83

pH B-Reactor	# Samples	Soluble Zinc Effluent mg/l	Effluent Cyanide mg/l	Sludge Density %
8.4	1	3.2	4.7	-
8.8 - 9.0	9	0.47	1.5	31
9.1 - 9.4	7	0.30	1.3	18
9.9 - 10.5	3	0.19	1.2	11

Iron addition was approximately 300 mg/l for all cases.

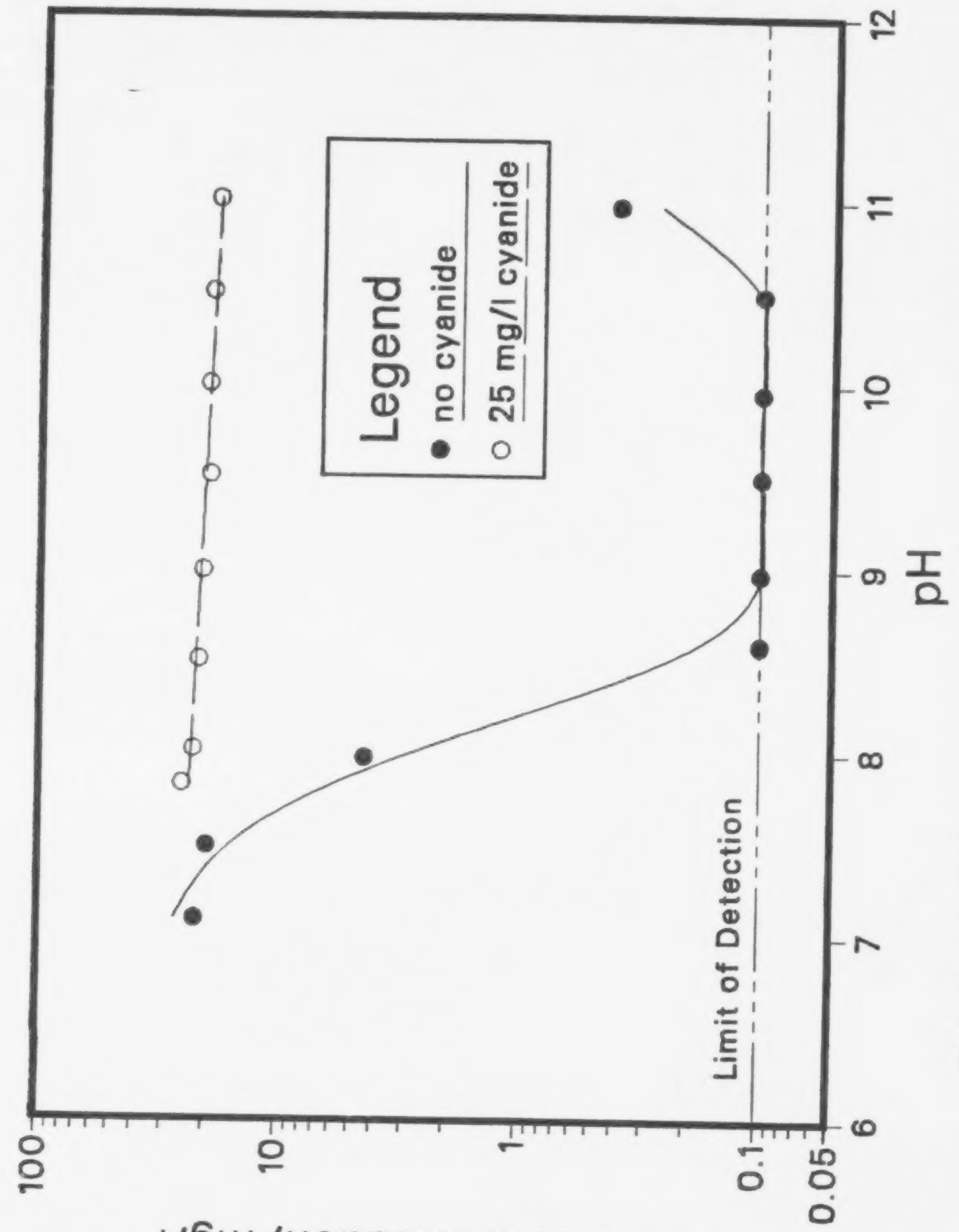
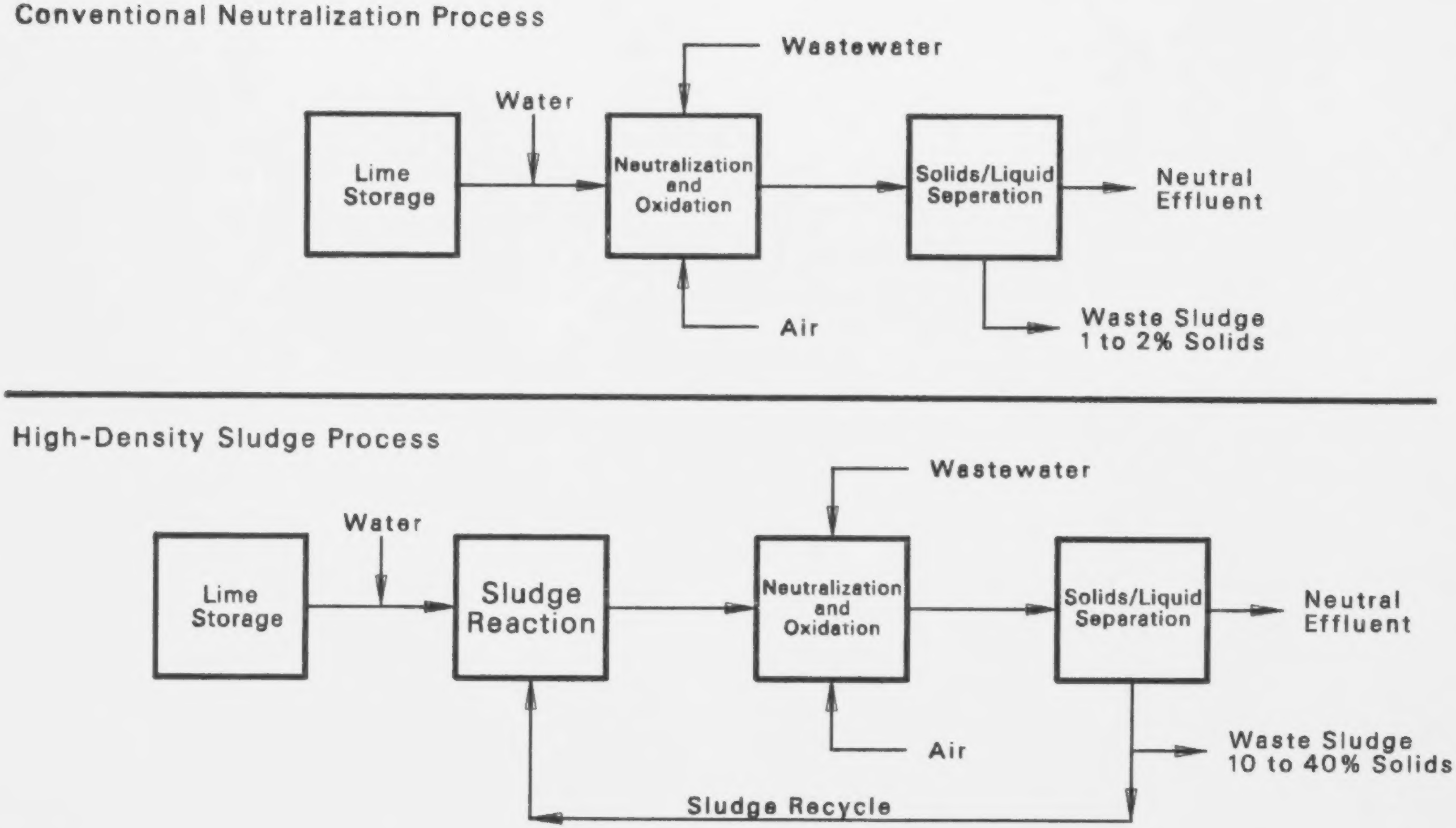


Figure 1. Effect of pH on Soluble Zinc in Wastewater With and Without the Presence of Cyanide


Conventional Neutralization Process

High-Density Sludge Process

Lime Storage
Water
Wastewater
Neutralization and Oxidation
Air
Solids/Liquid Seperation
Neutral Effluent
Waste Sludge 1 to 2% Solids
Lime Storage
Water
Sludge Reaction
Wastewater
Neutralization and Oxidation
Air
Solids/Liquid Separation
Neutral Effluent
Waste Sludge 10 to 40% Solids
Sludge Recycle

Figure 2. Block Diagram Comparing Conventional Neutralization and the High-Density Sludge Process

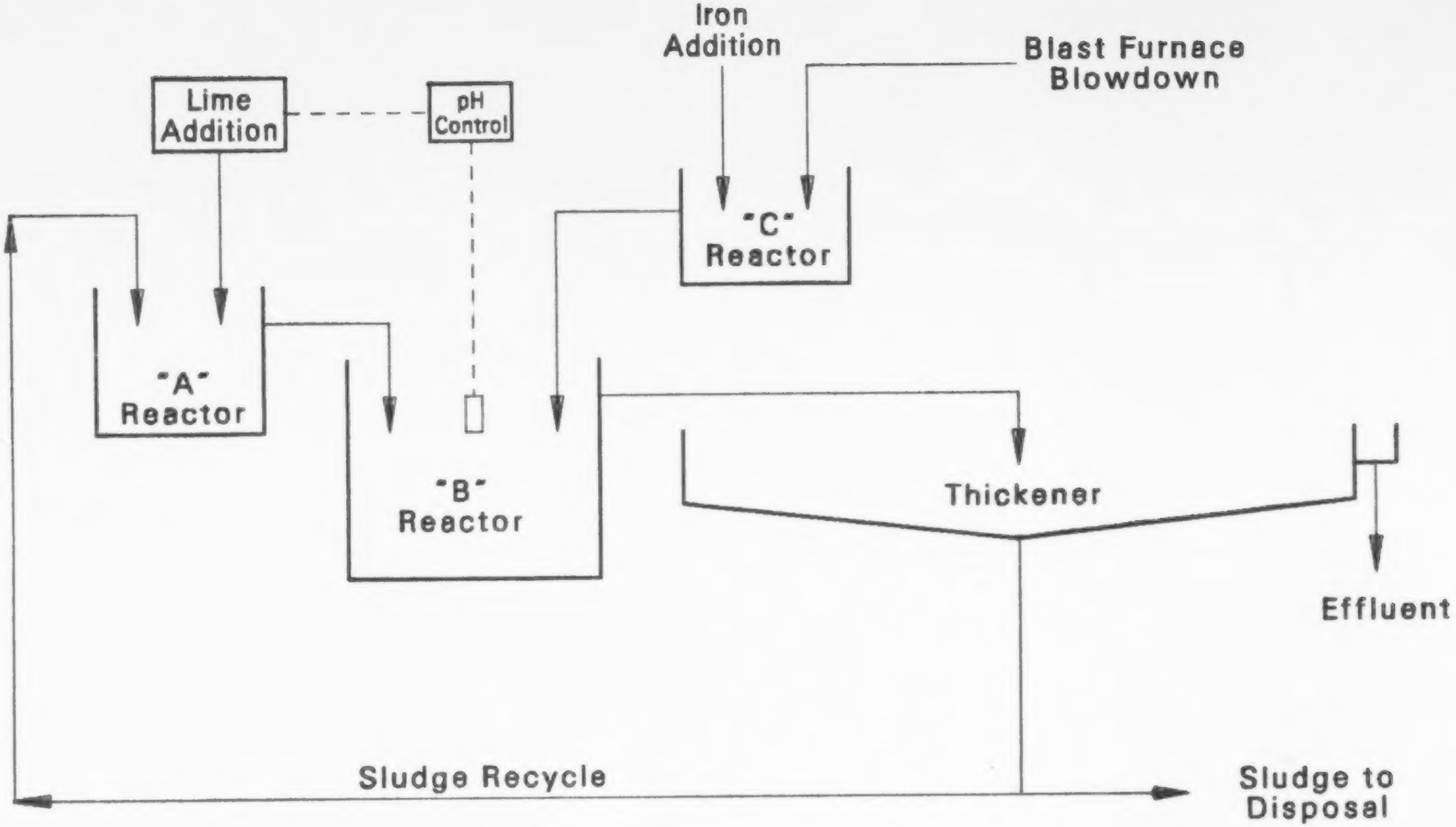

Iron
Addition
Blast Furnace
Blowdown
Lime
Addition
pH
Control
"C"
Reactor
"A"
Reactor
"B"
Reactor
Thickener
Effluent
Sludge Recycle
Sludge to
Disposal

Figure 3. The Modified High Density Sludge Process

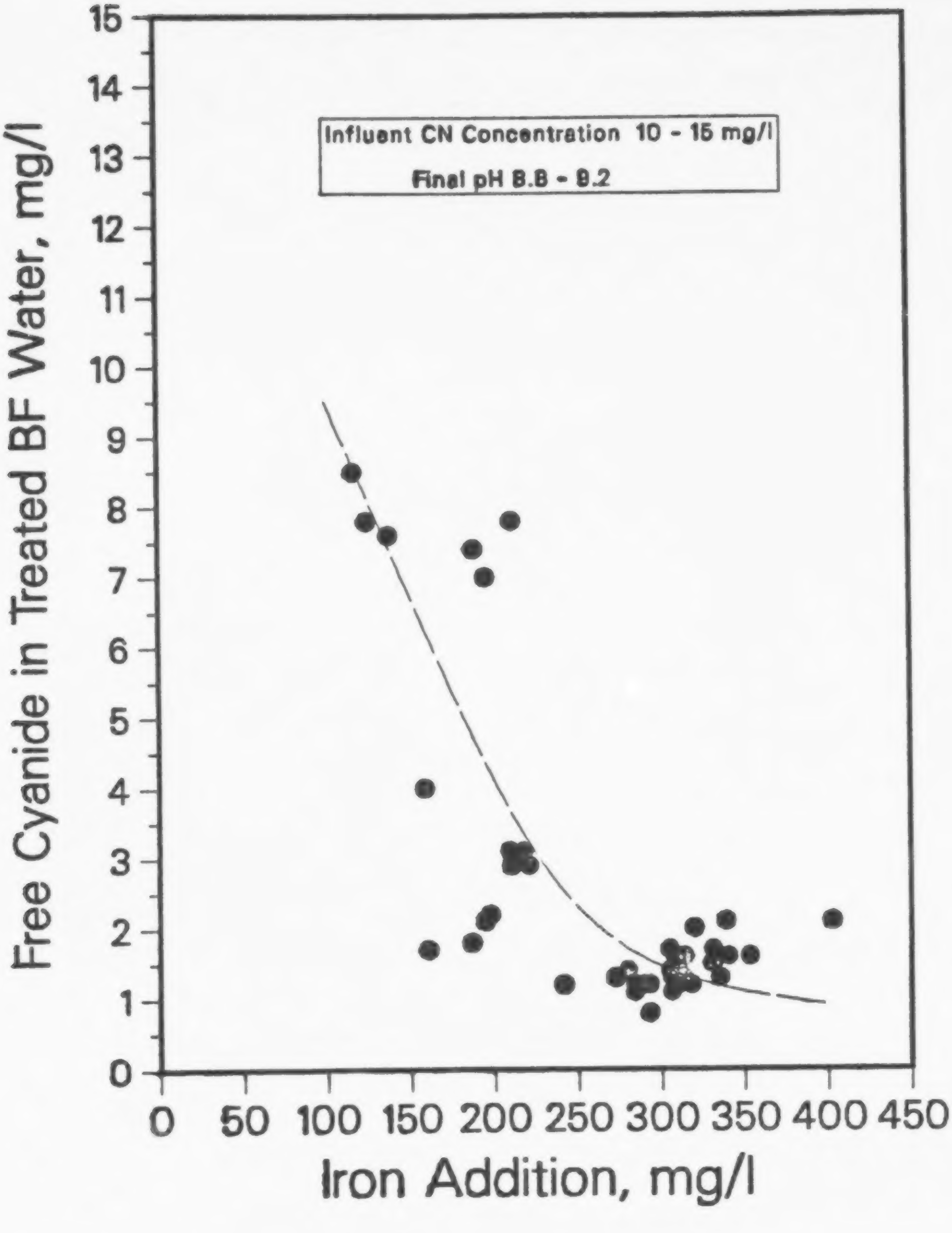


Figure 4. Free Cyanide Effluent Concentration as a Function of Iron Addition to Blast Furnace Blowdown

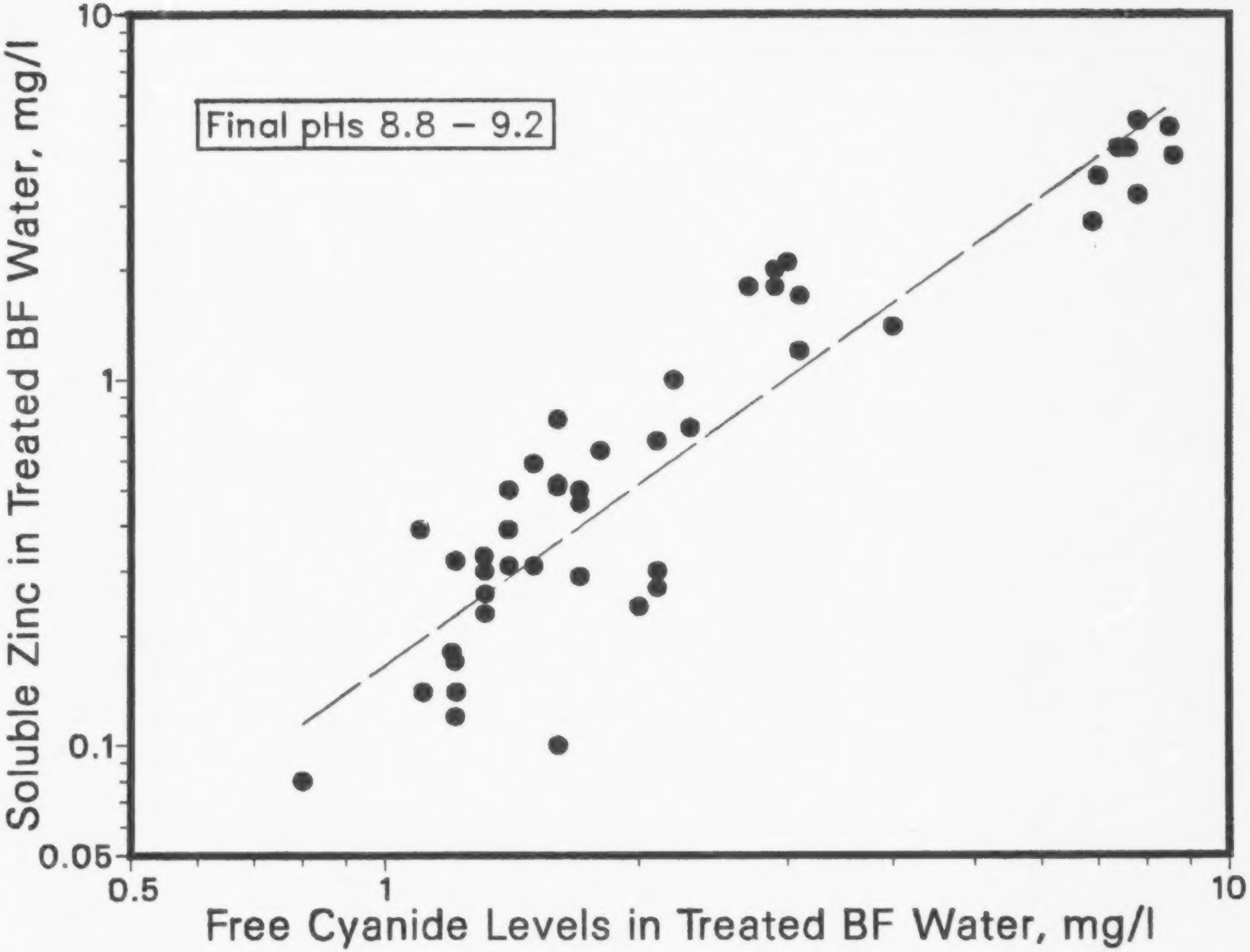


Figure 5. Concentration of Zinc in Treated Blowdown as a Function of Free Cyanide Concentration

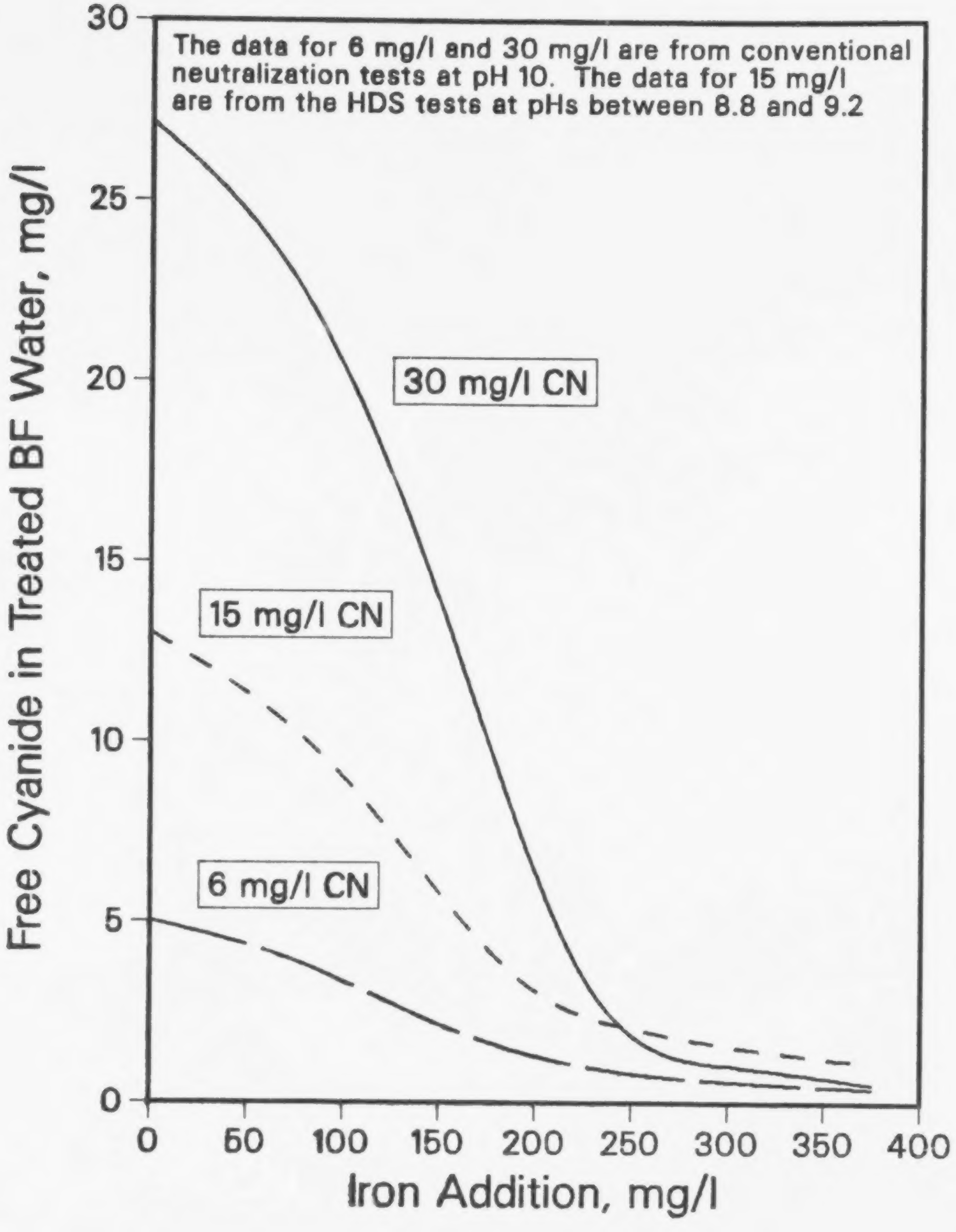


Figure 6. Effect of Inlet Cyanide Concentration on the Removal of Cyanide by Iron Addition

LTV STEEL'S*
TWIN STRAND SLAB CASTER
CLEVELAND WORKS
A SYSTEMS APPROACH TO INTEGRATED WATER TREATMENT

BY

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October 1984

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* LTV STEEL is the newly formed company which operates the joint facilities of Republic Steel Corporation and Jones & Laughlin Steel Corporation.

ABSTRACT

LTV Steel Company's Twin Strand Continuous Slab Caster at Cleveland, Ohio is an advanced, state-of-the-art installation.

This paper discusses the design criteria, selection processes and economic considerations involved in integrating the new slab caster's recycle water systems into the existing "once through" Steel Plant Water Treatment System. Consideration is given to the factors involved in deciding to upgrade the existing facilities as opposed to installing a new treatment system, e.g. concept design, labor requirements and other special considerations.

In addition to highlighting the caster water system design, biological control and innovative flume design and fume collection/suppression are discussed. Included are the wastewater characteristics and the special provisions for treatment, treatment flexibility, future operating permits impact and the economics as applied to other operating entities supplied by the existing water system.

Preliminary results from the first nine months of operating experience are discussed with the emphasis on chemical usage, corrosion inhibition, solids loading and a "look-back" critique of some problem areas.

Also discussed is the total recycle of all waters within the Steel Plant Complex as the second phase of this project.

With the current and projected proliferation of new continuous casting facilities, this paper is directed at those steel makers who face decisions regarding caster water treatment. Integration and use of existing water treatment facilities and total recycle of these waters offered LTV Steel many benefits which were not readily apparent at the onset of the study phase. Others may wish to contemplate a similar approach.

Water systems for continuous casting operations are critical to the overall operational efficiency of each installation. Republic Steel's decision to build a Twin Strand Slab Casting facility at the Cleveland District Steel Plant precipitated an in-depth study of the design criteria which would produce an advanced, state-of-the-art installation.

Water systems were a high priority item for investigation, and the decision was made early in the study phase to consider not only the design parameters which related directly to the caster, but all parameters which effect the Steel Plant Complex. This systems approach to water system design led to the integration of the Steel Plant's water treatment facilities and a caster installation which has exceeded all expectations.

This successful installation was dependent upon intense front-end planning which considered the impact of numerous items in establishing the required design criteria. Among the items considered were:

Climatelogical data
Environmental restrictions and projected requirements
Existing make-up and water quality
Manning requirements
Operational costs
Operation profiles - both present and projected
Maintenance profiles
Equipment redundancy
Utility usage and cost

The results of these analyses led to a two-phased approach to integrating the steel plant's water systems:

Phase I - Caster Recycle
Phase II - Total Steel Plant Recycle

HISTORY AND OVERVIEW

Prior to the caster installation, the Cleveland District Steel Plant was comprised as follows:

B.O.F. Shop
44" Blooming Mill
45" Blooming Mill
18" Billet Mill
12" Bar Mill
10" Bar Mill

Also included were the associated soaking pits and reheat furnaces. All received cooling waters, called service water (both contact and non-contact), from the Cuyahoga River via the River Water Pumphouse. This pumphouse also supplied a portion of the water and provided back-up capability for the cooling water requirements at No. 1 Coke Plant.

Prior to 1975, the steel plant discharged its wastewaters, after scale removal, to the river. The water supply systems could be described as follows:

River water (service water)
    Steel plant
    Coke plant
City water
Local recycle systems

In 1975, the Steel Plant Treatment Plant was installed. This treatment facility receives all direct contact wastewaters, including stormwater, from the steel plant area and, prior to caster start-up, was operated on a "once through" basis. The non-contact cooling water, with the exception of the bar mill reheat furnaces' water, is discharged directly through a 60" diameter sewer back to the river.

The treatment plant was designed hydraulically so that it could be modified both to accept wastewaters from a continuous casting facility, and also recirculate the treated wastewater and non-contact cooling water back to the entire steel plant via the existing service water distribution system. The treatment plant also dewaters the solids collected in the adjacent B.O.F. Suppressed Combustion System Treatment System. The treatment system consists of sedimentation in three 90'-0" diameter clarifiers, pressure filtration in twelve 16'-6" diameter deep bed filters and solids removal via six vacuum filters.

Since river silt and potential municipal sewage overflow are present in the Cuyahoga River in varying quantities (especially high, above 2,000 mg/l total suspended solids, T.S.S., during storm conditions where the high river flow stirs up silt and the municipal plants overflow) and the quality of the water returned to the river averages only 5 to 10 mg/l suspended solids, S.S., The Steel Plant Water Treatment Plant has, for the last six years, been cleaning up the Cuyahoga River. This has proved somewhat of a double-edged sword in that the improved quality of the river has led to a resurgence of aquatic life which intermittently causes fish plugging problems in screens and strainers resulting in down time in the mills, blast furnaces, etc. To ease the maintenance problems associated with these uncontrolled peaks of river silt and bio. load, considerable volumes of city water are used to replace "service water" (river water) in critical locations.

DECISION MAKING PROCESS

The decrease in bar product manufacturing at the Cleveland District, and the projected reduced operations of the blooming mills occasioned by the caster installation, would dramatically reduce both the hydraulic and process loading to the treatment plant. This reduction in process loading would adversely influence the efficiency of new treatment operations and add substantially to the operating cost/gal. of water treated in the facility. Further, a "stand alone" caster treatment facility would basically duplicate all the existing treatment plant equipment and double the operating and maintenance cost to the District. To build into the "stand alone" the flexibility already available at the existing treatment facility would be redundant and involve a much greater capital expenditure than could be justified in the circumstances.

After engineering and economic study of "stand alone" treatment facilities, it was decided to provide water treatment for the new continuous casting facility by recirculating through the existing treatment facility. The new process loading (100 mg/l S.S., 10 mg/l oil) and hydraulic loading (9000 GPM) were well within the original design parameters of the existing treatment facility, which was designed for SS loadings of 200-500 mg/l at a design flow of 27,500 GPM. Flows to the treatment facility were then in the 16,000 GPM range.

The project was to be two phased.

PHASE I CASTER RECYCLE

The initial phase permitted the mixture of continuous caster effluent (9000 GPM design, 12,000 GPM maximum) and the steel plant (hot forming) direct contact waters (approximately 16,000 GPM maximum). The mixture (25,000-28,000 GPM) would be treated for solids and oil removal in the existing treatment facility from which the effluent stream would be split, with one stream (9000-12000 GPM) directed over a new two-celled cooling tower and recycled back to the continuous casting facility via a new pumping system. The remainder of the treatment plant effluent (16,000 GPM) would be monitored for quality and discharged to the river through the existing outfall. The indirect cooling water from the B.O.F. hood cooling heat exchangers would continue on a "once through" basis and discharge through the non-contact water outfall.

PHASE II TOTAL STEEL PLANT RECYCLE

It was anticipated that, in order to comply with the EPA's new BATEA regulations, LTV Steel would need to recycle all water in the Steel Plant Complex. In order to accomplish this, Phase II projected enlarging the cooling tower with two additional cells, adding a steel plant recycle pump station and an indirect cooling water effluent pump station (Figure 2). The existing steel plant water distribution system would be isolated from all other water supplied, and all non-potable city water users within the steel plant converted to recycle water. This would include the indirect cooling water. A minimum blowdown was envisaged to maintain a chemical balance within the system. Make up to the system would be achieved by introducing river water on a demand basis into the clarifiers. Chemicals would be fed during both phases of the project to maintain the required water quality.

Chlorine for bacteriological control
Surfactant as a chlorine contact aid
Acid as required for pH control
Dispersant/Inhibitors as required.

The discussions, studies and process which led to the above decision can be broken down as follows:

Economic benefits
Operational benefits
Environmental benefits
Effect on other areas within the District
Overall cost justification

The items discussed were further divided into two areas; those whose cost savings were distinct and those whose cost savings were intangible, yet nevertheless clearly an item of effect, e.g. some of the items considered would clearly result in substantially reduced maintenance.

ECONOMIC BENEFITS

Among the items considered where tangible savings would result were:

City Water Savings

The single area of most potential cost savings was that of city water usage. These savings are indicative of the poor quality of service water, and because of it a study was made with the following conclusions and recommendations:

Total daily steel plant consumption of city water was approximately 3.46 million gallons. This could be allocated as follows:

Potable Users	0.61 MGD
Leakage	0.94 MGD
Non-Potable Users	1.91 MGD

Replacement of city water by recycle water on the non-potable users in the Steel Plant would result in an annual savings of approximately $450,000.

New Steel Plant Recycle Pumps at Recycle Cooling Tower

Replacement of the old river water pumps by new vertical turbine type pumps for recycle would result in substantial energy savings. A conservative estimate of the increase in efficiency of the pumps (15%) would realize an annual savings in the order of $70,000.

Reduced Sludge Volume at Treatment Plant

The introduction of recycle would result in a reduction of sludge volume at the treatment plant due to the elimination of river silt. This would realize a modest annual savings in the handling and hauling of this sludge. This savings reflected hourly costs only, and did not take into consideration future projected requirements and regulations or any escalation. Also, with land fill space at a premium, reduced sludge volumes would help conserve existing land fill areas. Other benefits realized due to the reduction in solids would be reduced power costs in the sludge handling equipment (vacuum filter, sludge pumps, mixers, etc.), and the resultant reduction in maintenance on these items due to reduced running time.

Reduced Chemical Usage

The need to maintain a satisfactory stability index to the caster recycle and the steel plant recycle as a whole would result in reduced chemical usage at the B.O.F. hood heat exchangers. The heat exchanger cooling water is presently being treated in order to reduce fouling, although this cooling system is "once through". Annual savings here approximate $60,000.

B.O.F. Heat Exchanger Maintenance

Discussion with the B.O.F. operational and maintenance personnel indicated that maintenance (due to fouling) was a continual and high cost item.

OPERATIONAL BENEFITS

Mill Down Time

Improved river quality has led to the re-establishment of aquatic life. This has in turn led to fouling/plugging problems in the strainers and screens. Installation of a recycle system would eliminate this problem. This could also be viewed as an economic benefit reflected by reduced production losses and maintenance time.

Control of Steel Plant Service Waters

Complete recycle of the steel plant from the treatment plant area would result in all recirculating waters for the Steel Plant Complex coming under the control of the treatment plant operators. Centralization of control and maintenance could only lead to cost reduction and increased efficiency in the departments presently responsible for these areas.

Reduced Maintenance

A new pumping system at the treatment plant would result in reduced maintenance at the existing River Water Pump House. A cleaner recycle water could only lead to reduced wear on the pumping and piping system, and reduce the time spent cleaning strainers.

Removal of Organics

Removal of organic loading due to the river water would be reduced, improving the working environment of the treatment plant and eliminating the noxious odors at times encountered in the treatment plant.

Purer Product Recovery

Elimination of the river silt from the scale pits and treatment plant sludge would result in a purer product being available for recovery in sintering or pelletizing operations.

Stability Index

Complete recycle of the steel plant area would produce a better quality water for all areas including the continuous caster. Controlling the recycle waters stability index would optimize the scale forming/corrosive tendencies of the water used. Further, the increased volume of the recycle water over that required for the caster alone can only improve the quality and controllability of the caster recycle, especially in view of the large percentage of steel plant recycle which would be used for non-contact cooling.

Reduction of Freeze Potential

A totally recycled steel plant, in addition to reducing thermal load to the river, would have the additional advantage in winter of recirculating water at a much higher temperature than is available at present. The heat pick up from the mills, B.O.F. heat exchangers, Continuous Caster, etc., in conjuction with a controllable cooling tower would lead to a suitable temperature being maintained in the recirculating water system. This elevated temperature would reduce the freezing potential of the service water distribution system. Also, a more stable temperature profile through the steel plant would minimize the seasonal thermal stratification problems normally encountered in this type of operation.

ENVIRONMENTAL BENEFITS

Reduction of Heat Load

Total recycle with minimum blowdown of cooled water would substantially reduce the heat load to the river.

Reduction of Solids, Oil and Grease Loading

The minimum blowdown envisaged for a totally recycled system, with the same treatment performence now encountered on a once-through basis, would reduce the solids and O & G loading to the river and meet BATEA regulations.

Stabilized Treatment

The minimized effects of upsets caused by river conditions (silt and organics) would lead to a more stable treatment process. The only river water to be introduced into the system would be make up which, on a net loading basis, would result, more often than not, in a negative value.

EFFECT ON OTHER AREAS

Coke Plant

Total recycle of the Steel Plant would result in the No. 1 Coke Plant non-contact cooling water being divorced from the present distribution system. A dedicated non-contact cooling water loop and associated pumps would be created to service the No. 1 Coke Plant.

25 Cycle Power

The elimination of the east side pump house would eliminate one of the last vestiges of costly 25 cycle power.

OVERALL COST JUSTIFICATION

The capital expenditure and operating cost saved by integrating the Caster Water Treatment into the existing Steel Plant Treatment Plant coupled with the savings to be realized by Phase II more than justified this two-phased approach. The tangible cost benefits from city water savings, reduced chemical usage, etc. anticipated with Phase II along with the reduced maintenance and manning requirement made this system's approach to integrated wastewater treatment the only viable economic choice.

IMPLEMENTATION OF PHASE I

CONTINUOUS CASTER WATER SYSTEMS

The Cleveland Caster has two distinct water systems. They are:

Mold and Machine Cooling Water - closed loop.
Spray/Indirect Cooling Water - open loop.

Mold and Machine Cooling Water System

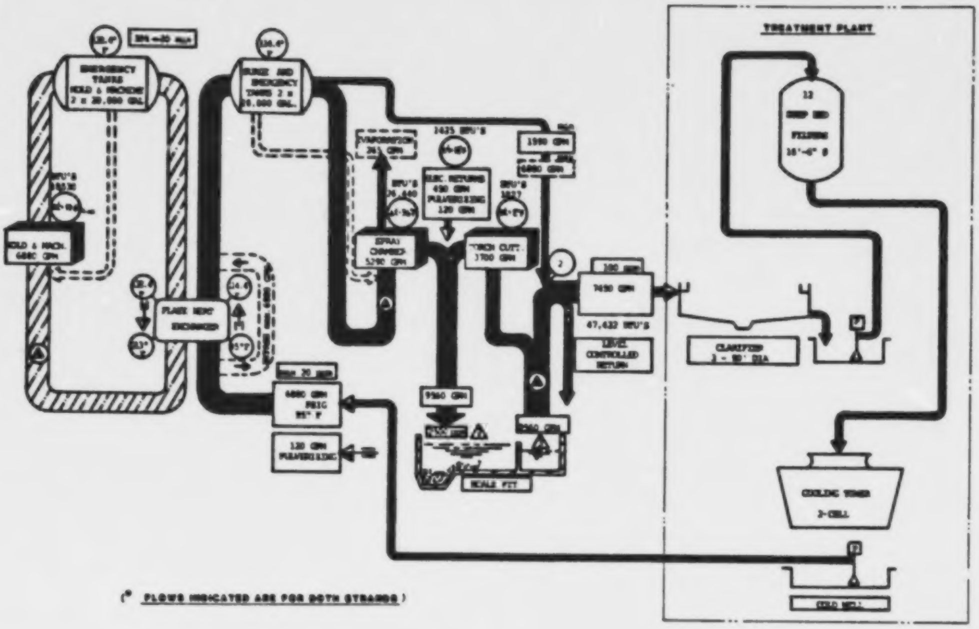
The extremely high heat transfer rates and surface temperatures of both the molds and machine necessitates the use of chemically treated, zeolite softened city water. Heat flux is such that even the least amount of powdery film deposit on the mold can cause "breakouts" and the ensuing production losses and high maintenance costs. This system is a closed loop, cooled indirectly through plate and frame heat exchangers by the spray water system (Figure 1).

The system uses a molybdate treatment for corrosion protection. Molybdate was chosen over chromate because of environmental considerations. Even though the system does not blow down and is a closed loop, normal operational leakage and accidental spills were felt to preclude any consideration of chromate treatment.

Spray/Indirect Cooling Water System

The spray water (Figure 1) is a multi functional system which does indirect cooling of the mold and machine waters, direct cooling of the cast slab and the machine externals, and scale conveying via flumes to a scale pit. These functions are all critical to efficient operations.

The spray water is clarified and deep bed filtered river water chemically conditioned to disperse oil, inhibit corrosion and solids deposition in addition to biological control. The resulting clean spray water is pumped from the treatment facility to the caster where it passes through the heat exchangers cooling the mold and machine water prior to being discharged into a flow-through elevated emergency storage tank. The


TREATMENT PLANT
EMERGENCY TANKS MOLD & MACHINE 2 x 20,000 GAL.
SURGE AND EMERGENCY TANKS 2 x 10,000 GAL.
MOLD & MACH. 6880 GPM
PLATE HEAT EXCHANGER
EVAPORATION 265 GPM
2425 BTU'S
ELEC. RETURNS 430 GPM PULVERIZING 120 GPM
1990 GPM
6880 GPM
BTU'S 26,460
BTU'S 3827
SPRAY CHAMBER 5290 GPM
TORCH CUTT. 3700 GPM
7450 GPM
47,432 BTU'S
LEVEL CONTROLLED RETURN
9360 GPM
6880 GPM FRIG 85° F
120 GPM PULVERIZING
SCALE PIT
12 DEEP BED FILTERS 16'-0" Ø
CLARIFIER 3 - 90' DIA
COOLING TOWER 3-CELL
COLD WELL

(* FLOWS INDICATED ARE FOR BOTH STRANDS)

FIG.1 CONTINUOUS CASTER WATER SYSTEMS

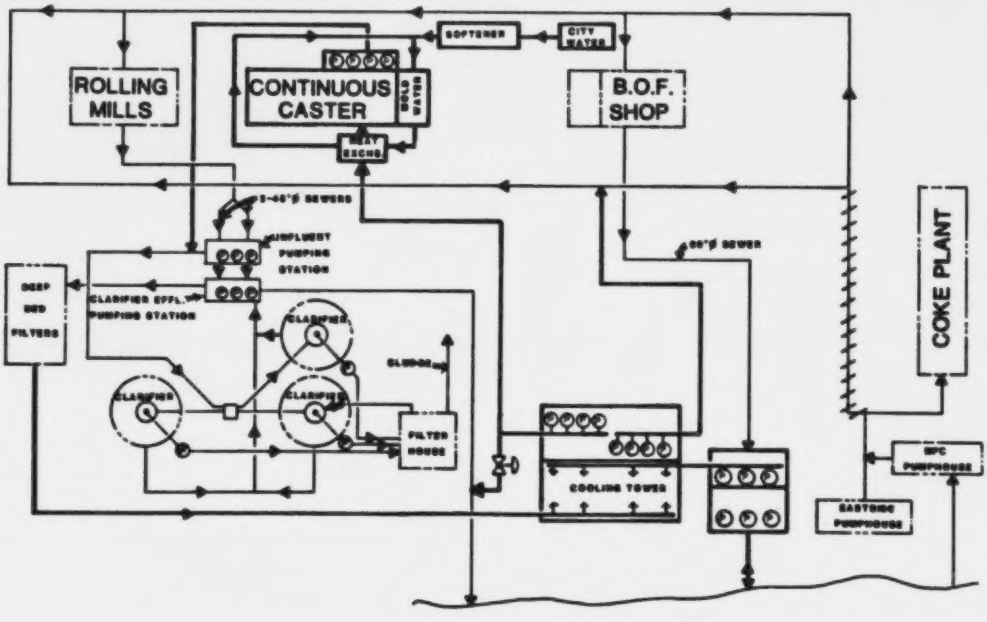

ROLLING MILLS
CONTINUOUS CASTER
MOLD WATER
HEAT EXCHG.
SOFTENER
CITY WATER
B.O.F. SHOP
2-48"Ø SEWERS
INFLUENT PUMPING STATION
CLARIFIER EFFL. PUMPING STATION
DEEP BED FILTERS
CLARIFIER
CLARIFIER
CLARIFIER
SLUDGE
FILTER HOUSE
60"Ø SEWER
COOLING TOWER
COKE PLANT
EASTSIDE PUMPHOUSE
NPC PUMPHOUSE
CUYAHOGA RIVER

FIG.2 PHASE II RECYCLE

tank discharge is pumped to increase the pressure to the slab cooling sprays, and the overflow directed to the scale conveying flumes for flushing to the scalping pit. The majority of the scale is settled in the scalping pit and the spray water pumped back, with a portion recycled through the scale conveying flumes to the treatment plant. It is then clarified, filtered, and cooled in an induced draft cross flow cooling tower prior to discharge to the cold well. Biological control is achieved by feeding sodium hypochlorite, while the inhibitor/dispersant is a custom blended proprietary chemical.

CASTER WATER SYSTEM DESIGN CONSIDERATION

Design of the caster water systems was given careful scrutiny with special attention to scale conveying flume design. To date, casters in general have been plagued by flumes which required digging out every down turn, flumes which overflow due to scale build up, flumes which in short are contra productive to efficient operations and contribute to treatment plant problems. Unless the flume is designed, and sufficient water is provided to produce velocities in the order of 10-13 f.p.s., sedimentation and plugging of the flumes will be a way of life. This criteria was met and to date no time has been lost due to scale build up. The scale ends up where it belongs in the scalping pit and the facility stays clean and productive.

An adequately designed scalping pit with superior scale removal characteristics was critical to the system design. Items of concern were:

Particle size distribution.
Trapping of hydraulic oil spills.
Scale removal efficiency.

A design value of less than 100 mg/l S.S. in the effluent was chosen as an acceptable loading to the treatment facility. Based upon the particle size distribution information available from other installations, this translated that anything larger than 60μ must be settled in the scalping pit. The scalping pit was then sized accordingly. The selection of an invert emulsion as hydraulic fluid and the hygroscopic characteristics of that fluid raised concerns with regard to possible filter blinding due to spills or leaks. Oil baffles and oil skimming equipment were installed to combat these eventualities. This has subsequently proved to be a minimal problem, basically due to excellent housekeeping and maintenance practices at the caster.

A grab-bucket gantry crane arrangement was selected, after careful consideration and analysis of the alternatives, to be the most efficient means of scale removal. The scalping pit has functioned excellently and, as a result, minimum impact due to scale has been evidenced at the treatment plant. Again, good housekeeping has played a major part.

Another design innovation worthy of mention is the flow through emergency tanks. In the past, emergency tanks have been captive, stagnant side-streams and havens for biological growth. The continuous flow-through feature of this design eliminates the potential for biological fouling and reduces freeze potential.

CHEMICAL SYSTEMS

Spray Water

Since system start-up, a chemical treatment program has been employed consisting of sodium hypochlorite feed for biological control, with addition of a dispersant/corrosion inhibitor and a surfactant/chlorine penetrant polymer. The sodium hypochlorite feed is determined by running chlorine residual tests each 8-hour turn and one chlorine demand test per day. Residual chlorine after the caster is consumed in the treatment plant clarifiers and sand filters before the portion of water not recycled back to the Caster is discharged to the river. Although a total year's data has not been collected at this time, there seems to be a 20-25% increase in demand when comparing cold weather and warm weather figures. Additionally, sodium hypochlorite is fed to the cooling tower to control algae growth on the distribution deck. Experimental tarpaulin covers for the deck appear to be promising in controlling this problem.

To date, biological control in the spray water system appears to be effective. Pressure drop across the plate and frame heat exhcangers has remained steady since start-up, indicating clean transfer surfaces in this critical area.

Corrosion control in the system has been harder to deal with. Current data shows a corrosion rate of approximately 15 mils/year and fouling of some small piping in the system has occurred. This problem, while of some concern presently, should resolve itself once Phase II recycle is implemented, allowing for a cycling up effect of corrosion inhibitors and much improved control. In general, water quality should stabilize during Phase II, as the effect of the Cuyahoga River on the system is minimized.

Mold and Machine Water

Chemical treatment of the caster's mold and machine water has been achieved with a two-product approach to control corrosion and biological activity within this closed loop. Environmental impact of potential spills from the mold water system was an important criteria when selecting the chemical treatment program to be used. Rather than use a traditional chromate based corrosion inhibitor, a molybdate treatment approach was chosen. Molybdate, in contrast to chromate, has no adverse biological effects on the environment should a discharge occur. Corrosion inhibitor levels are measured daily to maintain adequate corrosion protection. Make-up water consists of water softened through an ion exchange unit prior to introduction into the system in order to maintain low hardness levels, targeted at less than 20 ppm total hardness as calcium carbonate. Average hardness levels have been maintained at 2-3 ppm calcium carbonate.

Corrosion protection has also been excellent, with rates of .1 to .3 mils/year achieved on mild steel and 0 to .1 mils/year on copper alloy.

Bacteria colony counts are taken monthly. Desired levels of less than 100,000 organisms per millimeter are maintained using a proprietary biocide rather than free chlorine treatment to avoid system corrosion and migratory iron.

FUME COLLECTION

The uniformity of temperature and aluminum adjustment being critical to quality control and the castability of steel, an argon ladle stirring station has been installed at the caster. A hood complete with openings for scrap addition, temperature and steel sample hoist, aluminum wire feeding and an emergency argon lance has also been installed, with fume collection via a suitably sized baghouse. This baghouse served the dual purpose of collecting fumes from the tundish tilting station (where the used tundish is emptied of steel and slag and the refractory dumped) as well as the ladle stirring station.

The stirring station was given baghouse priority when in operation by means of automated dampeners. The tundish tilting station has proven to be a dirtier operation than was anticipated due to the selection of cold boards and sand as tundish working refractory. This arrangement has proven unsuitable due to the priority placed on the stirring station over the tundish tilting station. Accordingly, alterations are underway to provide a dedicated fume collection system for each area.

PRELIMINARY TRENDING

Although comparison with prior years is inconclusive due to variance in production levels and operation of equipment which has subsequently been shut down, preliminary trending indicates an improvement in treatment stability and a reduction in process loading with caster recycle alone (Figure 3). This trend, with Phase II still to be implemented, is encouragement that the decision to integrate the treatment systems was justified.

As can be appreciated, a moderate increase (20%) in treatment plant operating cost has been evidenced since the activation of the caster. However, this cost increase is minimal when compared to that which could have been anticipated with the operation of an additional "stand alone" caster treatment facility, even ignoring the capital cost savings. The implementation of Phase II will see further cost reductions due to economies in chemical usage and increased energy efficiencies, in addition to the many operational and maintenance benefits discussed previously.

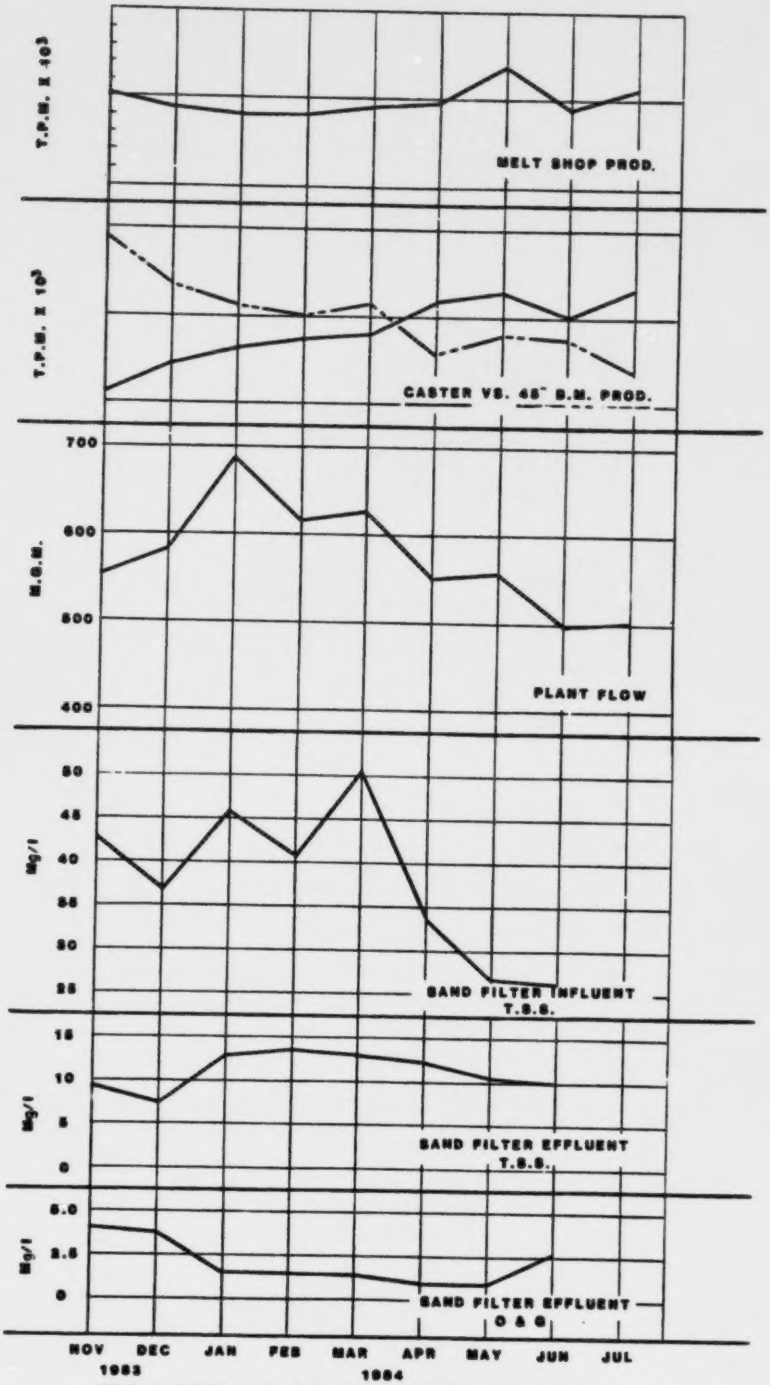


FIG.3 TRENDS SINCE CASTER START UP

A LOOKBACK CRITIQUE

As is normal in any start-up period, some problems have been encountered. Thankfully none of these have been of major proportions. However, they are worthy of mention.

CORROSION

The corrosion control of the piping system has been generally successful. However, in some small diameter lines where velocities are very low, plugging due to corrosion has occurred. Local corrosion control in these areas is being initiated as an interim measure. This problem should be eliminated with the advent of Phase II, complete recycle. Inhibiting chemicals can be economically maintained at much higher levels in a system which is completely recirculated.

COOLING TOWER

The cooling tower has performed in excess of expectations from a thermal standpoint. The open deck distribution basin has, however, encountered algae growth. The enclosing of this deck would have minimized the problem. Tarpaulin covers are being installed in retrofit as a means to minimize solar impact, but still provide the adequate access necessary for maintenance.

HEAT EXCHANGERS

The plate and frame heat exchanger's caused concern during start up due to pin hole leaks in the plates which were not discovered until the mold and machine system hardness started to elevate. This necessitated dumping the system and losing a valuable chemical charge. Also, it would have been preferred, from a hydraulic standpoint, to have the mold system pressure higher than that of the spray water (cooling water) system, so the minute leakages would have migrated to the "dirty" system. This was, in this case, not possible due to physical and dynamic considerations.

The choice of molybdate treatment was justified on this occasion alone due to the large volume of treated water which had to be dumped. A chromate dump could have been problematical as no means were available to reduce and precipitate the chromate.

LOW POINT DRAINAGE

Due to the physical layout of the facility, a portion of the mold and machine systems piping was of necessity below grade. System hardness problems caused by the leaking heat exchangers necessitated dumping the system prior to recharging. The system residual, left in the undrainable underground portion of the piping, resulted in a higher system hardness than would have been preferred, but well within the design limits. Low point drainage of the underground piping would have eliminated any possibility of elevated hardness levels. Also, some rust settled in this area during initial system flushing and was not eliminated from the system for some period after start up.

MOLD AND MACHINE SYSTEM

Problems with the mold and machine water system center primarily around system leaks that cause excessive make-up to the system and also excessive chemical consumption. With operating experience, these losses have been reduced (minimizing leaks in the system continues to be a high ranking goal at the caster). Careful inspection and maintenance of the plate and frame heat exchangers are also necessary to prevent instrusion of high hardness spray water into the mold water.

CONCLUSION

In conclusion, apart from the minor problems delineated above, the system has, from an operational and an environmental standpoint, exceeded all expectations and we look forward to an equally successful Phase II of this integrated approach to wastewater treatment.

The work described in this paper was not funded by the U. S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

COMPREHENSIVE BIOASSAY STUDIES FOR EVALUATING TREATED STEEL PLANT PROCESS WATER

Prepared by:

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ABSTRACT

Water quality testing of steel plant effluents normally involves measuring selected chemical parameters. In the case of Stelco's new Lake Erie Works steelmaking plant at Nanticoke, a comprehensive study was devised to measure the impact of treated process water on aquatic organisms. Test species chosen represent various trophic levels of the food web including standard aquatic test organisms and important indigenous species for acute and sub-lethal studies. The paper describes the main aspects of a continuing bioassay evaluation program and gives a four year summary of test results. The features of the program assisted in achieving consistent performance of water treatment facilities. The aim of the bioassay study is to confirm that the effluent meets water management objectives and regulations.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

INTRODUCTION

During the planning stage of a new steelmaking facility on the north shore of Lake Erie we made the decision to undertake a comprehensive bioassay evaluation of the plant effluent. The program started in the spring of 1980 at the same time as the plant began making steel. Studies have continued since then and the intensive work should be completed in 1985.

It was recognized early on that treated process water would be returned to the near shore water regime of the Lake. Based on other studies, it was shown that the plant discharge would have to share the Lake resources with such existing activities as commercial fishing, water supply and recreation. As a result only a high quality effluent would be acceptable.

Water quality of steel plant effluents is generally defined in terms of water chemistry parameters. But chemical examination alone does not provide sufficient information for a detailed assessment of discharge effects on receiving waters. The missing element is the effect on the aquatic biota. It follows that for a thorough evaluation a program should include studies that measure the responses of aquatic organisms when they are exposed to an industrial effluent. By combining water chemistry and aquatic bioassay tests a more complete picture is developed. These reference points aid in ensuring that receiving water quality is maintained. Accordingly, a comprehensive study was designed to confirm that water treatment design objectives were achieved and that regulatory requirements are being satisfied.

My aim then is to give you some background about the water management features of Stelco's Lake Erie Works steelmaking complex and provide details of a bioassay evaluation program.

WATER MANAGEMENT FEATURES

In June 1980, a new steelmaking facility started operations near the village of Nanticoke. The plant today is composed of a:

* dock to receive raw materials,
* blast furnace to make iron,
* steelmaking shop,
* continuous slab casting facilities,
* cokemaking and by-products plant, and
* facilities to treat process water.

The latest water treatment technology was applied and the program was based on five principles:

* minimize water discharge through recirculation,
* apply advanced water treatment technology,
* provide back-up facilities,
* use a single discharge arrangement,
* monitor water effluent for potential effects on aquatic organisms.

WATER RECIRCULATION

As an effective environmental strategy, recycled process water is used extensively in ironmaking and steelmaking processes. Water used for cleaning contaminated process gases is taken to settling devices which separate solids such as iron oxide and lime from the water. The solids are removed and stored for future reuse. Following chemical adjustments, the water is pumped over cooling towers to reduce the temperature. The cooled and partially cleaned water is returned to the process and the cycle is repeated. Approximately 85 percent of the process water is reused in this manner keeping most of the contaminants in the system. The other 15 percent of the water must be withdrawn as a blowdown to prevent pipelines from plugging up with scale.

FINAL WATER TREATMENT

For the final treatment step, a unique water purification plant was built. Following controlled steps, solids are settled out and dissolved contaminants are destroyed by a chlorination treatment process. High chlorine dosages chemically oxidize contaminants in the process water. The treated process water is then filtered and sent to a large holding pond. After a 7 day retention period, process water is discharged to Lake Erie via a small stream,Centre Creek. As an additional precaution, separate holding ponds were built so inadequately treated process water can be held in the case of an emergency until the water can be re-processed. These steps ensure that process water is adequately purified before discharge.

On the basis of plant design criteria, predictions of water effluent quality and impact studies on lake water, the Ministry of the Environment approved a discharge to Centre Creek and Lake Erie. The certificate of approval was conditional upon the fact that the discharge is to conform with the objectives set out in the Ministry's management policies of 1978 concerning mixing zones. Among other things, this means conditions within the mixing zone must not be rapidly lethal to important aquatic life. In response to these conditions our aim became to devise a suitable test program for establishing compliance with the Ministry's water management objectives.

MULTIDISCIPLINARY APPROACH

While aquatic bioassay testing is not new, the Lake Erie Works' program is unique. It is the first time a comprehensive and long term biological evaluation was undertaken with the aim to span the start to full production period. Also the study addresses possible lethal and sub-lethal effects on important indigenous and standard aquatic test organisms. Test species were chosen to represent different trophic levels of the food web, that is, the water flea will feed on algae while trout will, in turn, feed on the water flea.

Chemical analyses of effluent water were also done. Table 1 and 2. The study program was strengthened through inputs from IEC Beak, the Ontario Ministry of the Environment (MOE) and the Ministry of Natural Resources (MNR).

To accomplish the task, an IEC Beak mobile laboratory was located on-site at LEW just prior to the commencement of steelmaking operations. This was considered the best approach for a number of reasons:

* large volumes of effluent required for the numerous bioassay tests was readily available,
* the high cost of shipping and possible alteration of effluent characteristics during transportation was avoided,

- Lake Erie water as used for plant operations was available for test dilutions and control tests,
- the mobile site laboratory concept was cost effective and provided a central location for information exchange between all parties.

A logical sequence of laborat[illegible] testing was begun in late April 1980 by starting with acute lethal[illegible] bioassays.

ACUTE LETHALITY RESPONSE TESTING

A bioassay is termed acute when the test substance induces a response, usually death, from the test organism over a short period of time, normally 96 hours or less. In this study standard test species included rainbow trout, Salmo gairdneri (Richardson), the cladoceran, Daphnia magna (Straus) and the unicellular green algae, Chorella vulgaries. The indigenous species used for testing was the amphipod Gammarus faciatus (Say). Amphipods were collected from the bottom of Lake Erie using artifical substrates and maintained in a laboratory stock culture until required for bioassays.

Weekly 96 hour static bioassays using juvenile rainbow trout were conducted over a four month period during the summer of 1980. Similar tests were done in 1983 and 1984. These tests were performed according to the procedure outlined in APHA Standard Methods, 14th edition, 1975 and followed specific recommendations of the Ontario Ministry of the Environment.

No acute mortality was observed at a concentration of 100 percent final effluent during the four months of testing in 1980. In the 1983-84 test period the results for rainbow trout were similar except for sampling done during a temporary upset condition. Toxicity was observed for about eight days under cold weather conditions. More detailed studies suggested that toxicity resulted from abnormal levels of chlorine or chloramines. Table 3. Toxicity was eliminated by treating the water with sodium thiosulfate and removing residual chlorine. It appears winter conditions reduce the effectiveness of Pond #4 in stabilizing process water. The temporary winter effect is not considered critical.

In conjunction with trout tests, weekly 48 hour static bioassays using Daphnia magna were conducted for acute toxicity. Effluent effects on Daphnia ranged from non-toxic to mildly toxic in 1980. Increased toxicity during the 1983-84 study period corresponded with the temporary winter upset condition due to abnormal chlorine levels. The results mirrored the observation obtained from trout tests. This suggests that Daphnia toxicity may be a good indicator of conditions which are approaching an unsafe level for fish.

Three 96-hour continuous flow bioassay tests were conducted in 1980 with juvenile rainbow trout. A serial dilution system automatically delivered 1.5 litres of effluent and dilution water to each vessel every 14 minutes. The test was designed to determine the effects of possible variation in water quality. There was no mortality during any of the tests. The tests were not repeated in 1984 since static tests lead to the same conclusions.

Two short-term algal lethality experiments were conducted in full strength effluent. One involved the direct measurement of oxygen production when the algal cells were exposed to light. This test was used to measure the effect of treated process water on the photosynthetic activity. A second experiment involved an evaluation of growth rate. The test was setup in triplicates and conducted for 17-days. Cells were counted during this period. The results of both tests indicated that full strength effluent did not inhibit the photosynthetic activity or growth of Cholorella vulgaris.

The results suggest that algal populations in the lake mixing zone should not be affected, thus ensuring the availability of food for the next higher trophic levels. Conversely excessive blooming is not expected either. These tests were not repeated in 1984.

The benthic amphipod Gammarus faciatus was also used as a test organism for acute lethality testing. Gammarus bioassays were conducted under static conditions over a 96-hour period following procedures recommended by Clemens (1950) and Judy (1979).

Gammarus collected from Lake Erie were successfully maintained in the laboratory environment and exhibited normal behaviour patterns for laboratory held amphipods Clemens (1950). They were fed pre-soaked decaying maple leaves with the occasional addition of crushed trout pellets as a diet supplement.

Bioassays were conducted in 400 ml glass beakers. Each test vessel contained 300 ml of effluent. The amphipods had to be exposed to the effluent individually, since this species has cannibalistic tendencies (Clemens, 1950). A total of 10 amphipods were assayed at an effluent concentration of 100 percent. A similar number were used as controls. No acute mortality was observed during any of the tests. Therefore we may conclude that the organism will likely continue to reside in the mixing zone and definitely beyond. On the basis of these results it was not considered necessary to repeat the acute test particularly since the organism would be used in sub-lethal testing in 1980 and 1984 for evaluating effects on growth.

CHRONIC BIOASSAYS

Chronic bioassays measure less radical responses on organisms. Test organisms may be exposed for many generations to sub-lethal or chronic concentrations in studies designed to determine accumulative effects. Chronic toxicity may affect growth, reproduction, hatchability, etc.

Since the effluent was found to be generally non-lethal to aquatic organisms, the next step was to test the effluent for sub-lethal effects. Again, standard and indigenous test organisms were selected for studies which looked at:

- Reproduction Stress.
- Growth Rate Inhibition.
- Embryonic Development.
- Hatchability Success.
- Avoidance Behaviour.
- Taintability.
- Life Cycle Interference.
- Bioaccumulation.

For these studies it was decided to conduct the tests at an effluent concentration of 5% by volume to simulate conditions at the edge of the approved mixing zone. Lake Erie water was used for dilution.

The reproductive stress of Daphnia magna was examined during a 23-day period of exposure to this 5 percent effluent concentration. Young daphnids were quantitatively enumerated using the funnel method which was developed by Leduc and Ali in 1965. The results indicated that this concentration of effluent did not inhibit Daphnia reproduction in 1980.

The test was repeated in 1983 and 1984 using several different sources of dilution water. Water from a nearby industrial pumping station, intended to represent local receiving water has repeatedly produced chronic toxicity in controls and therefore has proven to be an unsuitable source for dilution water. High copper levels may have caused the unexpected results. Tests conducted with Lake Erie water from an alternate source have confirmed the 1980 results, giving no evidence of reproductive inhibition at a 5 percent effluent concentration.

The effluent effects on the growth rate of Gammarus faciatus were evaluated over a 22-day period. The amphipod's growth was assessed by counting the number of exoskeletons shed during moulting by each test organism. The results indicated that there was no significant difference between control and effluent setups in either 1980 or in 1984.

Fertilized yellow perch eggs collected from Lake Erie were exposed to full strength effluent in finely meshed chambers submerged in a continuous-flow tray system. The chambers were sampled daily to determine embryo development and larval survival from recently hatched eggs. After two weeks, all larvae had hatched and little mortality had occurred in control and effluent tanks. The 1980 study was repeated in 1984 with similar results.

The growth of juvenile rainbow trout was monitored for eight weeks. Again, there was no significant difference between effluent and control setups.

The flesh of the control and effluent exposed rainbow trout was analyzed for accumulation of heavy metals and specific organic groups. No increase in flesh contaminants was found in effluent exposed fish when compared to control fish.

A series of avoidance behaviour experiments were conducted using rainbow trout, smallmouth bass and yellow perch. Yellow perch is successfully harvested commercially from this area of Lake Erie while smallmouth bass is actively sought by anglers in the region. The avoidance apparatus was one designed by Beak and performed well.

The apparatus was designed to accommodate one fish at a time. Rainbow trout, smallmouth bass Micropterus dolomieui (Lacepede) and yellow perch, 22 to 26 cm in length, were tested. The yellow perch and smallmouth bass for this study were obtained by MNR from Long Point Bay. The rainbow trout were obtained from a private hatchery. Each test fish was left undisturbed in the conditioning tank for a minimum of 48-hours. Fish behaviour in the avoidance test tank was evaluated over a three-hour period. At the conclusion of the three hours, the inflowing effluent and control water solutions were reversed. The behaviours of the same fish was observed for another three-hour period under these new conditions. Possible external influences affecting the fish behaviour responses would be detected by the reversal of the test solutions. If the fish responded similarly in both cases then the possibility of extraneous factors which might be affecting the fish's response could be discounted. Equal flows of effluent and clean water (700 ml per minute) were maintained through a water column 15 cm in depth. Full strength effluent was the only concentration tested in 1980. The results suggested possible avoidance by trout but the response was not statistically significant.

Avoidance tests with rainbow trout and smallmouth bass were repeated in 1984 using larger sample sizes and several effluent concentrations. Trout displayed a significant avoidance response to full strength effluent but did not avoid a 5 percent concentration. Bass displayed no avoidance behaviour even at full strength. This suggests, as in 1980, that a lake mixing zone should not interfere with fish migration routes along the shoreline.

To assess the effluent for fish taintability, laboratory exposed fish and a selected fish species from the local aquatic environment was evaluated for flesh flavour impairment using sensory evaluation techniques. In the laboratory study, 3 year old rainbow trout were exposed to 4 non-lethal concentrations of effluent for a period of 48-hours. The field study involved the collection of yellow perch by MNR personnel from the discharge area off Centre Creek and a control site in Long Point Bay. Established Ministry of the Environment lake sampling stations were used for Centre Creek discharge and control site sample points. Fish tainting collections were made in mid-August, approximately 2.5 months after the initiation of the effluent discharge.

The test procedure followed the ASTM protocol used by MOE. Recommendations by Larmond (1977) were also used to improve the experimental design of the study.

Yellow perch were skinned and filleted within hours of collection. The fillets were wrapped in aluminum foil, placed in plastic bags, labelled and frozen.

Test containers used in the rainbow trout laboratory study were glass aquaria of 160 L capacity. Each aquarium accommodated two fish, total weight of approximately 400 g. The serial dilution system delivered 1.5 L of test solution to each container every 14 minutes. This flow rate plus the initial test container volume (140 L) was equivalent to approximately 1.1 L/g of fish per day. After an exposure period of 48-hours, the rainbow trout were sacrificed, skinned and filleted. The fillets were wrapped and frozen in a manner similar to the yellow perch samples.

Cooked fish samples were given to an eight member panel for evaluation. The results indicated that there was no significant taste difference between effluent and control water exposed fish. Rainbow trout tainting tests were repeated in 1984, using a larger taste panel, and similar results were obtained.

A full lifecycle experiment using the American flagfish Jordanella floridae (Goode and Bean) as the test species was conducted over a 130-day exposure period in 5 percent final effluent. The basic methodology for this chronic toxicity study parallels that of Sphehar (1976) and Sphehar et al (1978). Suggestions by Smith (1974) and Foster et al (1969) were also implemented in the experimental design.

The actual life cycle experiment was conducted in IEC Beak's Mississauga toxicity laboratory. Larval survivorship, growth rate and embryro hatchability were monitored during the period of exposure.

The study was initiated by exposing one week old larvae to control and effluent solutions. These larvae were offspring of adults maintained in IEC Beak's laboratory. The concentration of effluent chosen for this experiment was 5 percent although no acute mortality was observed in a 96-hour exposure of adult flagfish to full strength effluent.

A total of 60 larvae were exposed in two aquaria of effluent and control water set-ups. Each aquaria was 35 x 20 x 20 cm and held 14 L of test solution. The flagfish test was conducted during this study under semi-static conditions.

The test solutions were maintained at 24 ± 0.5°C and the aquarium lighting system was kept on a 16-hour light/8-hour darkness sequence for the duration of the study.

Larval growth was recorded monthly until sexual maturity was obtained. Survivorship was monitored daily throughout the test.

Spawning activitiy commenced shortly after sexual maturity was observed. Eggs were removed daily from the spawning substrates and placed in petri dishes held in an incubator. The hatchability success of the F_1 embryos was recorded and survival of newly hatched larvae was monitored for seven days.

Test results indicated that there was no detectable difference in flagfish larval survivorship, larval growth or egg hatchability between control and effluent tanks. This test was initiated in 1984 under flow-through conditions but results are not yet available.

Routine biomonitoring with trout was continued from 1981 through 1984. Pond #4 effluent exhibited no fish mortality during normal plant operation. Water treatment upset conditions were detected through bioassay testing and the early warning signs gave sufficient time to make plant adjustments. Any observed toxic effect was temporary in nature and was caused by above normal chlorine or chloramine levels. With the exception of a single short term abnormal start-up condition, the water quality in the lake mixing zone has remained in compliance. Normally, a nine-fold safety factor is available. Freeze-concentration bioassay studies undertaken in 1981 showed that contaminant concentrations may rise by this factor without becoming toxic to trout.

Chemical testing is done routinely. These tests have not identified any concerns and the effluent is in compliance with the approved conditions for the plant. Table 1 and 2.

CONCLUSION

The results of the biomonitoring study clearly indicate that the effluent from Lake Erie Works involving cokemaking, ironmaking, steelmaking and rolling is normally non-toxic to fish. Sub-lethal testing has not identified any threat to indigenous organisms residing in Long Point Bay as the result of the LEW effluent discharged at Centre Creek.

The intensive bioassay monitoring program will be completed in 1985. At that time we will have information on water quality pertaining to full operation of the steelmaking facility and the program will have addressed in five years of testing all phases of starting a new steelmaking complex.

TABLE 1

PLANT DISCHARGE

	1980 mg/ℓ	1981 mg/ℓ	1982 mg/ℓ	ALLOWED mg/ℓ
SUSPENDED SOLIDS	8.5	11.9	9.5	15.0
IRON	0.6	1.1	0.5	1.5
ZINC	0.02	0.09	0.06	0.6
LEAD	0.03	0.12	0.09	0.4
COPPER	--	0.05	0.03	0.11
PHOSPHOROUS	0.02	0.22	0.12	1.0

TABLE 2

PLANT DISCHARGE

	1980 mg/ℓ	1981 mg/ℓ	1982 mg/ℓ	ALLOWED mg/ℓ
AMMONIA	0.14	0.09	0.34	0.95
CYANIDE	0.06	0.04	0.07	0.1
PHENOL	<0.001	0.002	0.001	0.018
OIL	0.75	<1.0	---	6.3
RES. CHLORINE	N.D.	N.D.	0.28	0.5

TABLE 3

TROUT TOXICITY AND CHLORAMINE CONCENTRATIONS DURING WINTER UPSET CONDITIONS

	POND NO. 4 EFFLUENT		POND NO. 4 EFFLUENT WITH $Na_2S_2O_3$		CENTRE CREEK
TIME RELATIVE TO UPSET	TROUT LC_{50}* %	TOTAL CHLORAMINES MG/L	TROUT LC_{50} %	TOTAL CHLORAMINES MG/L	TROUT LC_{50} %
BEFORE	>100.0	0.7	-	-	-
DURING	37.5	2.9	>100.0	-	<100.0
	1.5	11.8	>100.0	0.6	-
	57.0	1.0	>100.0	-	>100.0
AFTER	>100.0	< 0.2	>100.0	-	-

*LC_{50} - SAMPLE CONCENTRATION (%) REQUIRED TO KILL HALF THE FISH

SESSION 2

AIR POLLUTION ABATEMENT

CHAIRMEN:

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VERIFICATION OF THE EFFICIENCY OF A ROAD-DUST EMISSION-REDUCTION PROGRAM BY EXPOSURE PROFILE MEASUREMENT

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ABSTRACT

As part of an alternative particulate emission-reduction plan (bubble) approved for U. S. Steel's Fairless Works at Fairless Hills, Pennsylvania, a program to control road-dust emissions was mandated. A road-dust sampling program and calculations of dust-emission rates by predictive equations showed that sufficient amounts of controllable dust were available at four paved road segments to provide the required emission decrease. However, as part of the bubble approval, U. S. Steel was required to verify the predicted uncontrolled emission rates through actual emission measurements and to show that the required emission decrease could be achieved by vacuum sweeping.

To perform the required emission measurements, U. S. Steel designed and fabricated a state-of-the-art exposure profiler and developed an operating system. Measurements of actual emissions both before and after implementation of the control program were made. At the same time, surface-loading and silt-content data and vehicular-activity data were obtained for use with the predictive equation to estimate an emission rate. This study has shown that actual measured emission rates attested to the validity of predicted rates both before and after initiation of the control program.

The road sweeping program reduced the surface loading and silt content sufficiently to accomplish the required decrease in road emissions, thus providing a low-cost alternative to process emission control.

INTRODUCTION

Particulate emissions from the United States Steel Corporation (USS) Fairless Works (Fairless Hills, Pennsylvania) are governed by regulations developed by the Pennsylvania Department of Environmental Resources (PaDER). Because particulate emissions from the stacks of a process source were in excess of those allowed under PaDER regulations, an emission trade (bubble) was developed. Under the terms of the bubble, the excess particulate emissions from this source were to be offset by lower emissions at other process sources and by a program to reduce fugitive road-dust emissions by 138 pounds per hour (lb/hr) for each of two operating process units. Three pounds of road-dust emission reduction were required for each pound of excess emission at the stacks. The bubble was approved and became effective on January 8, 1983 (1)*.

To develop information for use in designing a road-dust emission-reduction program, plant roads were sampled to determine surface-dust loadings and silt contents. These data were used, along with vehicular-activity data, to calculate emission factors and emission rates of material smaller than 30 micrometres for 20 road segments. Sufficient amounts of controllable road dust were found at four paved road segments (A, C, D, and F in Figure 1) to provide an emissions trade-off for operation of either or both process sources. The emission-control program prescribed by PaDER for those segments required vacuum sweeping on a twice-per-week (weather permitting) schedule. Also as part of the plan, USS was required to verify the predicted uncontrolled emission rates through actual emission measurements and to show that the required emission reduction could be achieved (2).

DESCRIPTION OF USS EMISSION-MEASUREMENT SYSTEM

The USS road-emission measurement system consists of five major components.

1. An exposure-profile tower
2. An upwind sampler
3. Wind instruments and recorders
4. Vehicle-speed indicator
5. Conventional high-volume sampler

Particulate concentrations over a vertical cross section of the plume generated by vehicular traffic are measured with an exposure profiler located about 5 metres from the downwind edge of the test road. The exposure-profiler has four automatically controlled isokinetic samplers mounted on a 10-metre tower. The total air flow at each sampler is determined by a digital flow totalizer.

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* See References.

A single automatic isokinetic sampler is operated at about 10 metres from the upwind road edge. Concentrations measured by the upwind sampler are subtracted from those measured at each level on the profiler.

Wind speed and direction are monitored on a tower located near the profiler to ensure that sampling is conducted within specified limits.

During each test, observations are made of vehicular activity at the test site. Each vehicle passing during the test is categorized according to vehicle type and speed. An indicating recorder is used for speed measurement.

A conventional high-volume sampler located downwind of the road is operated at a flow rate of 20 standard cubic feet per minute (SCFM) to provide for visual inspection of filter loading as an indicator of test completion.

Computer-controlled scanning electron microscopy, with special operating techiques developed by USS (3), is used to evaluate the size, shape, and number of particles of various size fractions in the 0.2- to 75-micrometre range.

EMISSION-MEASUREMENT SITE DESCRIPTION

A site for measurement of uncontrolled road emissions was selected on road C (Figure 1) and was approved by PaDER. Among the factors considered in selecting this site were the availability of sufficient space to place the sampling devices, separation from structures that would interfere with air flow, and prevailing wind direction. Road C at the test site is a two-lane black-top road with shoulders of soil and gravel. Traffic is composed of a typical steel-mill mix ranging from cars and light trucks through 18-wheel flat-bed tractor-trailer trucks and Euclid-type earth movers. The area surrounding the site is grass covered, which prevents interference from localized wind-blown dust.

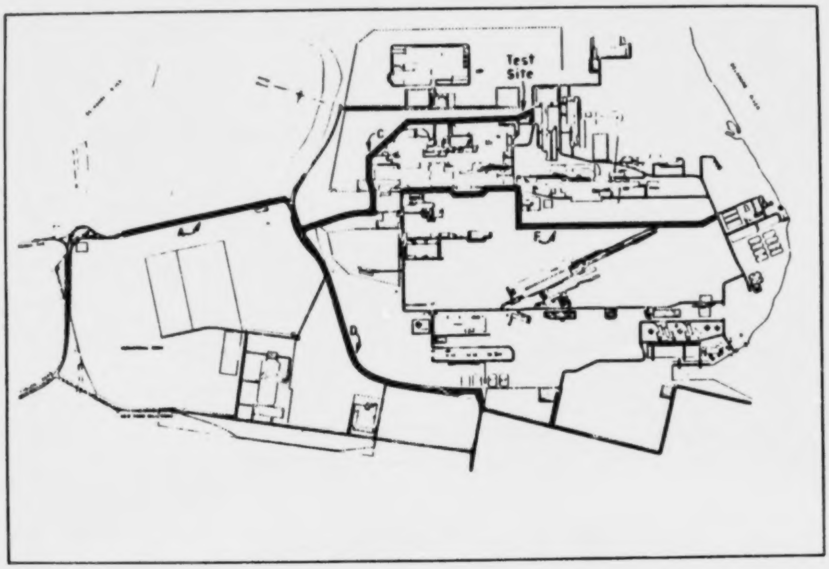

Figure 1. Fairless Works Roads and Exposure-Profile Test Site

SAMPLING PROGRAM

Based on a previous study (4) greater variablility can be expected in emissions data collected during tests of uncontrolled paved roads, rather than controlled paved roads. For this reason, ten exposure-profile tests were performed before vacuum sweeping and five tests were completed after initiation of the control program.

To determine the characteristics of the aggregate materials on the road surface that may be disturbed by vehicular passage, the traveled portion of the road was sampled frequently both before and after initiation of the control program to determine surface loading, and the aggregate samples were analyzed for silt content.

EMISSION MEASUREMENTS BEFORE VACUUM SWEEPING

Ten runs of the exposure-profiling equipment were conducted to measure uncontrolled road emissions. Wind direction and speed data recorded during each of those runs were assessed against established criteria to determine the validity of each run. This assessment showed that six of the ten runs were conducted under acceptable conditions. It was also shown that the automatic isokinetic controllers maintain sampling velocities that closely track the mean wind speed. Data collected during the six valid runs included total air-volume sampled, total dust capture, total particulate (TP) concentrations, weight percent of dust smaller than 30 micrometres as determined by computer-controlled scanning electron microscopy, and vehicular traffic.

The measured uncontrolled road-emission rate was determined as indicated in Table 1. The average TP concentration at each sampler position and the average weight percent of dust smaller than 30 micrometres were used to calculate the concentration, at each sampler, of particulate matter smaller than 30 micrometres (PM30). Subtracting the upwind PM30 from the PM30 concentration at each profiler position (P-1 through P-4), the concentration of dust contributed by the road was determined.

An exposure index, E, was calculated for each profiler position and plotted, Figure 2, against sampler height. A curve was fitted to these points by means of a polynomial regression analysis, which also provided an estimate of the intercept with the X-axis. The area under the curve, determined graphically, yielded a vertical exposure profile of 0.720 metre milligrams per square centimetre (m mg/cm^2). Converting this value to pounds per mile (lb/mile) and dividing by the average number of vehicles over the six runs gave an emission factor of 0.177 lb/vehicle mile. With an average of 47.6 vehicles per hour during the six runs, the measured uncontrolled emission rate was 8.43 lb/mile hour (Table 1).

TABLE 1. EXPOSURE PROFILE OF ROAD C BEFORE VACUUM SWEEPING

	Sampler Position				
	P-1	P-2	P-3	P-4	UW
Average TP, ug/m^3	297	241	250	238	232
Average wt % <30 um	77	83	78	80	81
Average PM30, ug/m^3	229	200	195	190	188
Road Dust, ug/m^3	41	12	7	2	
E^a, mg/cm^2	0.126	0.045	0.025	0.009	

Measured Emission Rate

$$\frac{0.720 \text{ m mg/cm}^2 \times 35.48}{144 \text{ vehicles}} = 0.177 \text{ lb/veh mile}$$

$$0.177 \text{ lb/veh mile} \times 47.6 \text{ veh/hr} = 8.43 \text{ lb/mile hr}$$

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^{a}E, mg/cm^2 = $\frac{\text{Road Dust, ug/m}^3 \times \text{Air Vol., ft}^3}{26.412 \text{ cm}^2 \text{ Nozzle Area}} \times \frac{1 \text{ m}^3}{35.315 \text{ ft}^3} \times \frac{1 \text{ mg}}{1000 \text{ ug}}$

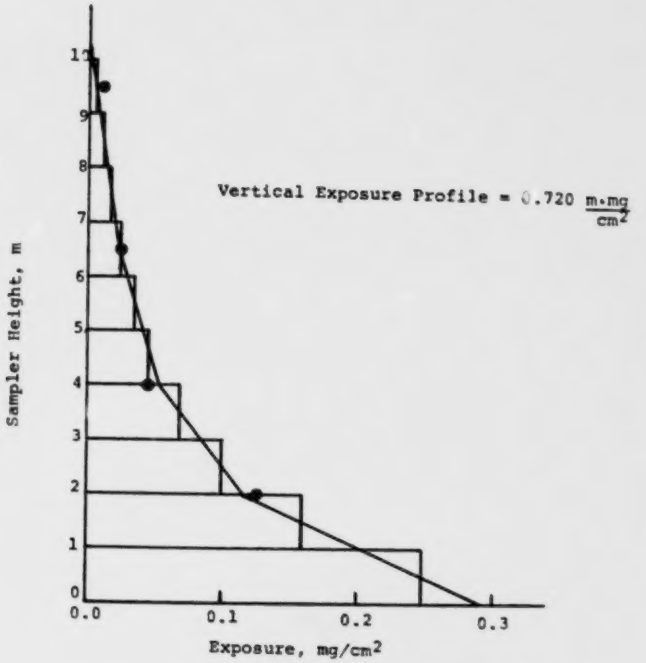

Figure 2. USS Fairless Works Road C
Exposure Profile Before Vacuum Sweeping

PREDICTION OF EMISSION BEFORE VACUUM SWEEPING

Road C was sampled frequently for surface-loading and silt-content prior to the start of the vacuum-sweeping program. The average surface loading and silt content, uncontrolled, were 270.4 lb/mile and 8.95 weight percent, respectively. These data, along with observed traffic, were used in the Midwest Research Institute (MRI) equation for paved road emissions (5) to predict an uncontrolled emission rate for road C. The calculations, shown in Table 2, resulted in a predicted uncontrolled emission rate of 8.46 lb/mile hour.

TABLE 2. PREDICTED EMISSION RATE CALCULATIONS BEFORE VACUUM SWEEPING ROAD C

Predicted Emission Rate (MRI Equation)

Emission Rate, = $(0.09)\ (I)\ (4/n)\ (s/10)\ (L/1000)\ (W/3)^{0.7}$ (Vehicles/hr)
lb/mile hr

where:

I = 3.5 for paved road with soil-gravel shoulders
n = Number of lanes
s = Silt Content, wt %
L = Surface Loading, lb/mile
W = Vehicle weight, tons

ER(cars) = $(0.09)\ (3.5)\ (4/2)\ (8.95/10)\ (270/1000)\ (1.5/3)^{0.7}\ (22.1)$
= 2.07 lb/mile hr

ER (pick-up) = $(0.152240)\ (2.5/3)^{0.7}\ (13.2)$ = 1.77 lb/mile hr

ER (6-wheel) = $(0.152240)\ (5/3)^{0.7}\ (6.6)$ = 1.44 lb/mile hr

ER (10-wheel) = $(0.152240)\ (15/3)^{0.7}\ (0.7)$ = 0.33 lb/mile hr

ER (18-wheel) = $(0.152240)\ (35/3)^{0.7}\ (3.0)$ = 2.55 lb/mile hr

ER (Euclid) = $(0.152240)\ (30/3)^{0.7}\ (0.3)$ = 0.23 lb/mile hr

ER (Other) = $(0.152240)\ (0.5/3)^{0.7}\ (1.7)$ = 0.07 lb/mile hr

Total = 8.46 lb/mile hr

EMISSION MEASUREMENTS AFTER VACUUM SWEEPING

Five runs of the exposure-profiling equipment were conducted to measure road emissions after initiation of the twice-per-week vacuum sweeping program. Four of the five runs were conducted under acceptable wind direction and wind speed conditions.

The measured controlled road-emission rate was determined as indicated in Table 3. The average TP concentration at each sampler position and the average weight percent of dust smaller than 30 micrometres were used to calculate the concentration, at each sampler, of particulate matter smaller than 30 micrometres (PM30). With a single sampler at the upwind site, the particulate concentration of the approaching wind is necessarily assumed to be homogeneous. However, the fact that average TP and PM30 values at profiler positions P-2 through P-4 are smaller than values observed at the upwind sampler suggests that TP may be stratified. Thus, it is not surprising to find cleaner air at profiler positions P-2, P-3, and P-4, all of which are physically higher than the upwind sampler.

TABLE 3. EXPOSURE PROFILE OF ROAD C AFTER VACUUM SWEEPING

	Sampler Position				
	P-1	P-2	P-3	P-4	UW
Average TP, $\mu g/m^3$	230	183	187	169	191
Average wt % <30 um	83	73	79	87	83
Average PM30, $\mu g/m^3$	191	134	148	147	159
Road Dust, $\mu g/m^3$	32	-25	-11	-12	
E^a, mg/cm^2	0.139				

Measured Emission Rate

$$\frac{0.630 \text{ m mg/cm}^2 \times 35.48}{232 \text{ vehicles}} = 0.096 \text{ lb/veh mile}$$

$$0.096 \text{ lb/veh mile} \times 47.3 \text{ veh/hr} = 4.54 \text{ lb/mile hr}$$

$$^a E, \text{mg/cm}^2 = \frac{\text{Road Dust, ug/m}^3 \times \text{Air Vol., ft}^3}{26.412 \text{ cm}^2 \text{ Nozzle Area}} \times \frac{1 \text{ m}^3}{35.315 \text{ ft}^3} \times \frac{1 \text{ mg}}{1000 \text{ ug}}$$

Subtracting the upwind PM30 from the PM30 concentration at profiler position P-1, the concentration of dust contributed by the road was determined. An exposure index, E, was calculated for position P-1. An exposure index of zero was assumed at about the height of the upwind sampler (3 metres). A line connecting these two points was extrapolated to ground level (Figure 3) and a vertical exposure profile of 0.630 m mg/cm^2 was obtained.

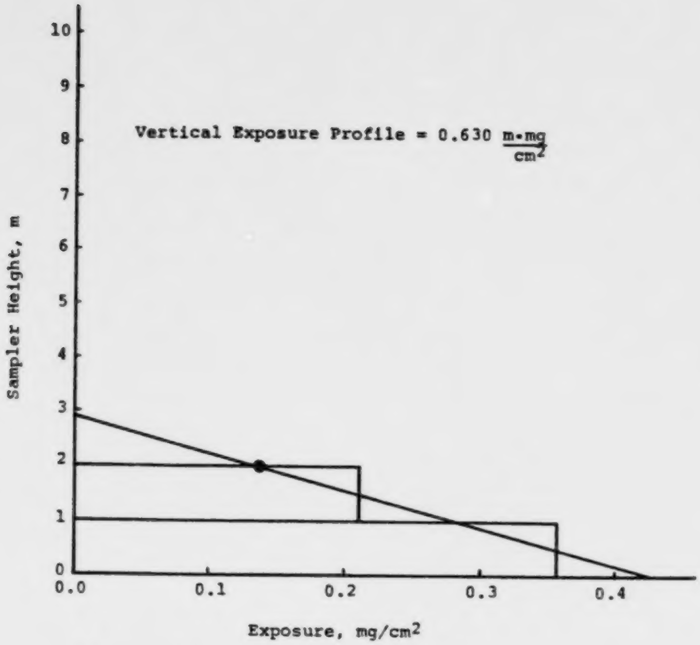

Figure 3. USS Fairless Works Road C Exposure Profile After Vacuum Sweeping

Converting this value to lb/mile and dividing by the average number of vehicles over the four runs gave an emission factor of 0.096 lb/vehicle mile. With an average of 47.3 vehicles/hour during the four runs, the measured controlled emission rate was 4.54 lb/mile hour (Table 3).

PREDICTION OF EMISSIONS AFTER VACUUM SWEEPING

Road C was also sampled frequently for surface-loading and silt-content after initiation of the vacuum-sweeping program. The average surface loading and silt content were 65.2 lb/mile and 16.2 weight percent, respectively. Those data, along with observed traffic data, were used in the MRI equation for emissions from paved roads to predict a controlled emission rate for road C. The calculations, Table 4, resulted in a predicted controlled emission rate of 4.44 lb/mile hour.

TABLE 4. PREDICTED EMISSION RATE CALCULATIONS AFTER VACUUM SWEEPING ROAD C

Predicted Emission Rate (MRI Equation)

Emission Rate, lb/mile hr = $(0.09)\ (I)\ (4/n)\ (s/10)\ (L/1000)\ (W/3)^{0.7}$ (Vehicles/hr)

where:

I = 3.5 for paved road with soil-gravel shoulders
n = Number of lanes
s = Silt Content, wt %
L = Surface Loading, lb/mile
W = Vehicle weight, tons

ER(cars) = $(0.09)\ (3.5)\ (4/2)\ (16.2/10)\ (65/1000)\ (1.5/3)^{0.7}\ (20.6)$
= 0.84 lb/mile hr

ER (pick-up) = $(0.066339)\ (2.5/3)^{0.7}\ (14.2)$ = 0.83 lb/mile hr
ER (6-wheel) = $(0.066339)\ (5/3)^{0.7}\ (6.1)$ = 0.58 lb/mile hr
ER (10-wheel) = $(0.066339)\ (15/3)^{0.7}\ (0.2)$ = 0.04 lb/mile hr
ER (18-wheel) = $(0.066339)\ (35/3)^{0.7}\ (4.9)$ = 1.81 lb/mile hr
ER (Euclid) = $(0.066339)\ (30/3)^{0.7}\ (1.0)$ = 0.33 lb/mile hr
ER (Other) = $(0.066339)\ (0.5/3)^{0.7}\ (0.2)$ = 0.01 lb/mile hr

Total = 4.44 lb/mile hr

SUMMARY OF MEASUREMENTS AND PREDICTIONS

The road surface-loading and silt-content data for the road C test site (Table 5) show that the vacuum-sweeping program was effective in lowering the amount of aggregate material from 270 lb/mile to 65 lb/mile (76 percent decrease), and the silt loading from 24.2 lb/mile to 10.5 lb/mile (57 percent decrease). Because this section of road C was relatively clean before sweeping, the efficiency of the vacuum sweeper was not as great as would be expected at roads with heavier dust loadings.

The average exposure-profile sampling time required to obtain adequate filter-dust loadings for size analyses was about 3 hours before vacuum sweeping and almost 5 hours after vacuum sweeping. These long sampling times are indicative of the cleanliness of road C.

The average hourly vehicular count was constant at about 47 vehicles per hour before and after initiation of the control program.

A comparison of the predicted and measured emission rates both before and after vacuum sweeping shows that the measured values obtained with the exposure profiler verify the rates predicted by the MRI equation.

TABLE 5. SUMMARY OF RESULTS BEFORE AND AFTER VACUUM SWEEPING OF ROAD C

	Before Vacuum Sweeping	After Vacuum Sweeping
Road-Surface Dust		
Loading, lb/mile	270	65
Silt, wt %	8.95	16.2
Silt, lb/mile	24.2	10.5
Exposure Profile Average Sampling Duration, hours	3.03	4.90
Average Vehicle Count, vehicles/hour	47.6	47.3
Emission Rates		
Predicted, lb/mile hr	8.46	4.44
Measured, lb/mile hr	8.43	4.54

EMISSION REDUCTION CREDITS FROM THE ROAD EMISSION-CONTROL PROGRAM

Surface-loading and silt-content data obtained in 1982 at road segments A, C, D, and F (2) are shown in Table 6 along with loading and silt data representing the current values following implementation of the vacuum-sweeping program at roads A, C, and D, as well as current data for road F which is now cleaner because it is no longer used as a slag-haul road. Although road F is now cleaner, it will be included in the vacuum-sweeping program in compliance with the operating permit requirements.

TABLE 6. SURFACE-LOADING AND SILT-CONTENT DATA

Road Segment	Uncontrolled 1982 Loading, lb/mile	Uncontrolled 1982 Silt, percent	Controlled 1983 Loading, lb/mile	Controlled 1983 Silt, percent
A	2893	4.3	33.8	19.4
C	3296	11.4	57.8	16.2
D	4222	3.5	1610	3.4
F	22270	7.6	848	13.5

Uncontrolled emission rates from road segments A, C, D, and F were previously predicted using MRI equations, and as shown in Table 7, totaled about 816 lb/hr. Using the same traffic data as were used in the prediction of uncontrolled emission rates, and current values for surface loading and silt content, controlled emission rates were calculated (Table 7), totaling about 80 lb/hr. The net reduction in the predicted emission rate was about 736 lb/hr, which is substantially in excess of the required 276 lb/hr.

TABLE 7. USS FAIRLESS WORKS ROAD-EMISSION SAMPLING PROGRAM EMISSION REDUCTION CREDITS RESULTING FROM PAVED ROAD EMISSION-CONTROL PROGRAM

Road Segment	Emission Rate, lb/hr Uncontrolled 1982	Controlled 1983	Reduction
A	72	4	68
C	533	7	526
D	25	9	16
F	186	60	126
Total	816	80	736

ERC for 2 Process Units = 276 lb/hr
Excess Emission Reduction = 460 lb/hr
Total Reduction = 736 lb/hr

Thus, this work has verified, by emission measurement, that the predictive equation is applicable, and through the use of the verified equation that a 90 percent reduction in road-dust emissions was accomplished at Fairless Works.

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5. C. Cowherd, Jr., R. Bohn, and T. Cuscino, Jr., "Iron and Steel Plant Open Source Fugitive Emission Evaluation," EPA-600/2-79-103, U. S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina, 27711, May 1979.

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THE RELATIVE EFFECTIVENESS OF A DUST SUPPRESSANT FOR USE ON UNPAVED ROADS WITHIN THE IRON AND STEEL INDUSTRY

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ABSTRACT

A water based, oil-resin emulsion was formulated and its relative effectiveness to control dust from unpaved roads was determined at a coke and iron producing plant. Exposure profiling, surface aggregate and silt analyses, as well as time lapse photography were used to evaluate the performance of this new dust suppressant. In addition, optimal dilution ratios and application rates were determined by the field study.

An economic analysis for the on-site production of the emulsion by an iron and steel plant was also carried out. This analysis included the costs of production by means of a low volume batch process and a large volume continuous operation.

INTRODUCTION

Because of the potential contribution of in-plant, open-dust sources on ambient particulate levels and the potential economic advantages of controlling these emissions, substantial efforts have been made by the steel industry to develop a cost-effective method of control for these sources. The generally accepted method used for this purpose has been to apply commercially available chemical dust suppressants or water to unpaved roads, storage piles, parking lots, and other open, exposed areas.

This approach has proved to be very successful, especially when oil-resin/water emulsions have been used. However, this control method is still somewhat expensive since large quantities of the suppressant are often needed and water alone is not very cost-effective since adequate control would require very frequent applications. This prompted the industry to initiate research to develop or formulate an oil-resin/water emulsion that would effectively reduce airborne fugitive dust and could also be produced on-site at the iron and steel plant.

A generic suppressant of this type was successfully formulated, as part of this study, and tested on an unpaved road at Shenango Incorporated, a coke and iron manufacturing facility located on Neville Island near Pittsburgh, Pennsylvania. Its formulation, relative effectiveness, and cost-benefit analyses are described in this paper.

The field test was conducted during the months of September, October, and November, 1983. Surface aggregate and silt analyses, exposure profiling, and time lapse photography were used to evaluate the performance of the Generic 1 formulation. In all instances, its effectiveness and overall performance were compared to a well-known, commercially available oil-resin dust suppressant.

THE GENERIC FORMULATION

IDENTIFYING AVAILABLE RESINS AND PRESCREENING

The logical steps required to determine whether a new formulation was possible were: first, a suitable resin had to be identified; then, it was necessary to formulate a successful emulsion. In an attempt to locate sources of resin throughout the United States, especially those available near steel producing regions, a questionnaire was mailed to 75 oil refineries or allied industries.

Oil-resin samples were received and screened for their suitability as suppressants. The criteria used for screening included viscosity, tackiness, ease of emulsification, availability, geographic location of source, cost, environmental acceptability, etc.

BASE STOCK SELECTION AND GENERIC FORMULATION

Initial attempts to emulsify the various resins were conducted in the laboratory and many individual emulsions were formulated. Of those preliminary formulations, one resin was selected for further work. This material is derived from a Pennsylvania crude oil, and according to the manufacturer, is readily available in large quantities upon request.

A number of generic formulations were made using this base stock. The differences between formulations were achieved by varying the type and percent stabilizer, the type and percent surfactant, and the amount of resin base stock used. The functions of each of these components are listed in Table 1. Generally, the resin comprised between 40 and 60 percent of the total emulsified concentrate.

TABLE 1. OIL-RESIN/WATER EMULSION COMPONENTS

Components	Function
1. Oil-Resin	1. Agglomerates Soil Particles
2. Surfactant	1. Emulsifies Resin 2. Allows Wetting of Road Surface 3. Facilitates Penetration Into Soil 4. Prevents Phase Separation of Emulsion
3. Stabilizer (Anti-Settling Agent)	1. Permits Long-Term Storage of Concentrate, Prevents Skin Formation 2. Permits Dilution With Hard Water
4. Water	1. Suspension/Dilution Medium

The final formula was selected empirically. The major parameters considered were ease of emulsification, stability of concentrate (lack of phase separation), stability of emulsion when diluted, and ease of dilution. Table 2 shows the general requirements of a resin emulsion.

STUDY DESIGN AND METHODOLOGY

BASELINE DATA COLLECTION

On September 19, 1983, a roadgrader was used to scarify to a depth of six to eight inches. Then the road surface was allowed to equilibrate for a short period. Normal traffic flows were permitted during this time. This allowed the surface aggregate to settle and established a smooth, compact road surface. Subsequent percent silt measurements and visual inspection verified the return to relatively normal conditions.

On September 26, 1983, the measurement of baseline data was started. Numerous loose surface aggregate samples were collected and ten successful exposure profiler tests were conducted.

Once the percent silt (all particles less than 75 μm) and the emission factors for the uncontrolled (no chemical treatment) road were obtained, the Generic 1 dust suppressant was applied.

TABLE 2. REQUIREMENTS OF A GOOD OIL-RESIN EMULSION

Make-Up

1. Environmentally Acceptable Components
2. Approximately 50 to 60 Percent Natural Resin
3. 1 to 3 Percent Surfactant
4. 0 to 2 Percent Stabilizer (Anti-Settling Agent)*
5. Approximately 40 Percent Water

Use

1. Easily Miscible With Water
2. Stable When Diluted With Hard Water
3. Good Soil Penetration Properties
4. Low Solubility After Curing
5. Moderate Tack for Soil Bonding

Storage

1. Stable (No Phase Separation or Skin Formation)
2. Compatible With Anti-Freeze Agent
3. Freeze/Thaw Stability

*Optional

CHEMICAL APPLICATIONS

Chemicals were applied to both test sections (see Figure 1) on two separate occasions during the study. Therefore, two distinct exposure periods were observed. The first lasted 23 days and the second encompassed 30 days. Period one allowed comparison of a single application, while the second period permitted observations of the cumulative effect of both applications.

Application ratios, along with the pertinent application dates, are listed in Table 3. The relative location of each chemical and the approximate length of each test section, as well as the treated background areas, are depicted in Figure 1. These background areas were treated throughout the study to avoid possible interferences caused by track-in or wind blown emissions.

Figure 1 Map of the Commercial Product and Generic 1 Test Sections

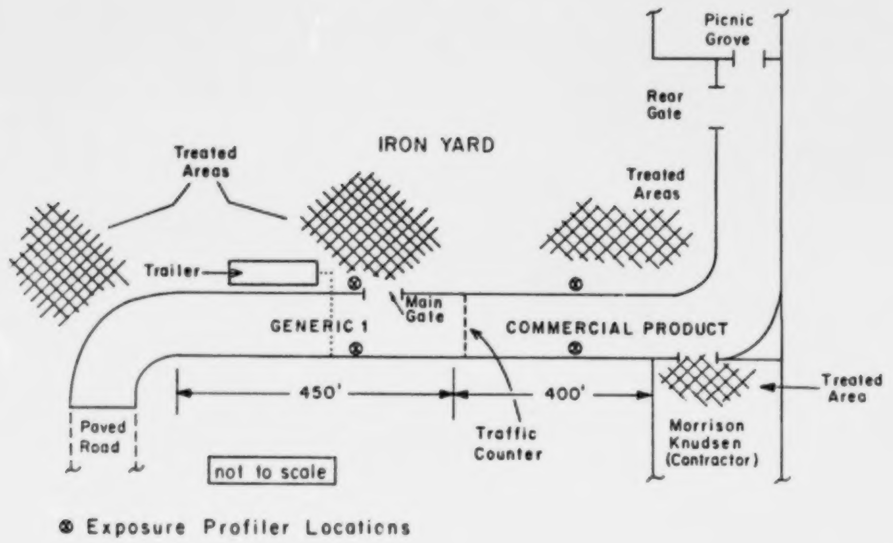

Picnic Grove
Rear Gate
Treated Areas
IRON YARD
Treated Areas
Trailer
Main Gate
GENERIC 1
COMMERCIAL PRODUCT
450'
400'
Treated Area
Paved Road
not to scale
Traffic Counter
Morrison Knudsen (Contractor)
⊗ Exposure Profiler Locations

TABLE 3. SUPPRESSANT DILUTION AND APPLICATION RATES FOR GENERIC 1 AND THE COMMERCIAL PRODUCT

Generic 1 - Road Section 1

Application Date	Dilution Ratio (Gal.)	Application Rate (Gal./Yd.^{2})	Ground Inventory
10/8/83	1:9	0.512*	0.051 Gal./Yd.^{2}
10/30/83	1:12	0.361**	0.028 Gal./Yd.^{2} + residual

Commercial Product - Road Section 2

Application Date	Dilution Ratio (Gal.)	Application Rate (Gal./Yd.^{2})	Ground Inventory
10/8/83	1:9	0.516*	0.052 Gal./Yd.^{2}
10/30/83	1:12	0.359**	0.028 Gal./Yd.^{2} + residual

*Applied in three separate passes with time allowed for sufficient penetration between each pass.

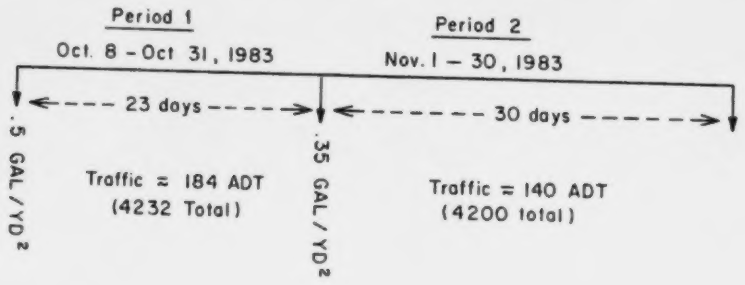
**Applied in two separate passes with time allowed for sufficient penetration between each pass.

EXPOSURE PERIOD COMPARISONS

Traffic and Precipitation

A schematic comparison of the two exposure periods is shown in Figure 2.

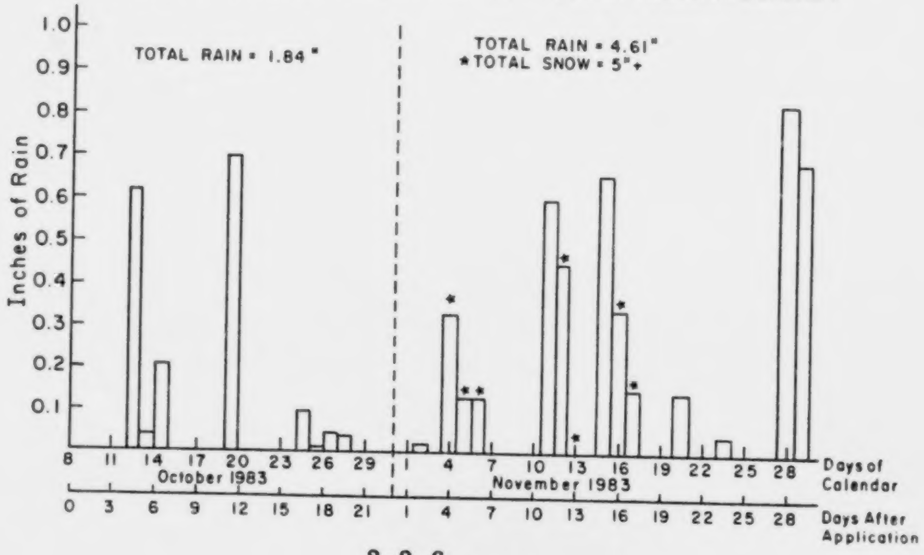
Figure 2 Schematic Comparison of Application Periods


Period 1
Oct. 8 - Oct 31, 1983
Period 2
Nov. 1 – 30, 1983
23 days
30 days
.5 GAL / YD²
.35 GAL / YD²
Traffic = 184 ADT
(4232 Total)
Traffic = 140 ADT
(4200 total)

Although the length of exposure in days is different, total traffic counts for the two periods are approximately equal. This is because the average daily traffic (ADT) tended to decrease toward the latter part of the study.

Rainfall comparisons, however, are quite different. Total rainfall for Period one was 1.84 inches, while 4.61 inches fell during Period two. Additionally, Period two experienced more than five inches of snowfall. Temperatures recorded at Shenango proper confirmed at least four definite freeze/thaw cycles during the month of November (Period two). This kind of information (freeze/thaw) is especially useful since it allows a comparison of the behavior of Generic 1 and the commercial product during the colder months of the year. A graphic presentation of rainfall for the two exposure periods is presented in Figure 3.

Figure 3 Rainfall Occurrence-Commercial Product/Generic I



Profiling, Silt Analyses, and Time Lapse Documentation

Silt analyses, exposure profiling of airborne particulate, and time lapse filming for each exposure period were performed whenever possible. Unfortunately, exposure profiling and time lapse documentation were not completed as planned in the latter half of the second period due to weather conditions. Only a partial comparison for this time span was possible. Therefore, profiler data presentation and subsequent interpretation is mainly limited to the first application period.

Silt sampling and analyses were conducted throughout the entire experiment. Comparisons of relative effectiveness using this parameter are complete. Table 4 compares exposure periods for all evaluative parameters used during the study.

TABLE 4. COMPARISON OF TREATMENT PERIODS DURING FIELD TESTS OF THE GENERIC 1 DUST SUPPRESSANT, SHENANGO INCORPORATED, 1983

Period 1 (23 days)	Period 2 (30 days)
1. Traffic Counts	1. Traffic Counts
2. Surface Aggregate Collection	2. Surface Aggregate Collection
3. Silt Analyses	3. Silt Analyses
4. Exposure Profiling	4. ----
5. Time Lapse	5. ----

EXPOSURE PROFILER

All profiling procedures and associated analyses were performed by Energy and Environmental Management (E^2M), Pittsburgh, Pa.

System Description and Meteorology

Road dust emissions were measured using a profile sampling system (profiler) that collects samples of the dust plume generated by vehicles passing on a road segment near the testing site. The system is designed to obtain samples at five levels of the plume and defines the vertical profile of dust particles' flux due to road emissions. Two key features of the profiler are that it is directional and isokinetic. The profiler is directed into the wind and collects particles from the source of interest, rather than peripheral activities. In addition, near isokinetic flow rates (relative to the wind speed) are maintained, which ensures that the collected dust sample is representative of the emissions and is not biased due to particle size. To ensure consistency among tests, criteria suggested by Midwest Research Institute (MRI)(1) were used to evaluate the validity of profiler tests.

To facilitate obtaining valid tests with light and variable wind speeds, sampling was stopped when the wind direction was not within the bounds of a valid test (±22½°). Traffic was also supplemented to increase the number of passes when the testing conditions were appropriate.

RESULTS AND DISCUSSION

AGGREGATE AND SILT LOADING COMPARISONS

Figures 4 through 7 compare the total aggregate, total silt, fine silt, and respirable silt loadings for the unpaved road test sections before and after treatment with the generic and commercial suppressants.

Total aggregate is important to consider since it represents the loose surface material available for vehicular abrasion. This abrasion causes fractionation of larger particles, thus, more silt is formed.

Silt, defined as all particles less than 75 μm, is an important parameter because it represents the material on the road surface that can become airborne through vehicular traffic or wind action.(1) Therefore, it represents the road's potential for airborne emissions. Fine silt, defined as all particles less than 45 μm, is important when comparing relative effectiveness because it represents the material that can become airborne and undergo long-term transport. Respirable silt, defined as the particles of less than 10 μm, represents the material that would be expected to have the most potential impact on human health.

Inspection of the graphs indicates that Generic 1 and the commercial product are quite comparable, especially for the respirable silt category (0 to 10 μm).

Figure 4 Generic I vs a Commerical Product - Total Aggregate Control (All Sizes)

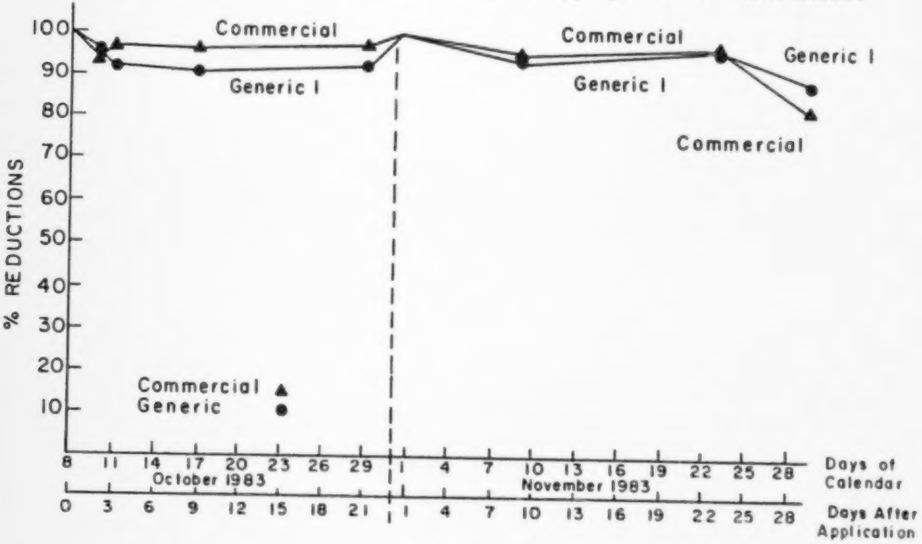


Figure 5 Generic I vs a Commercial Product - Total Silt Control (0μm to 75μm)

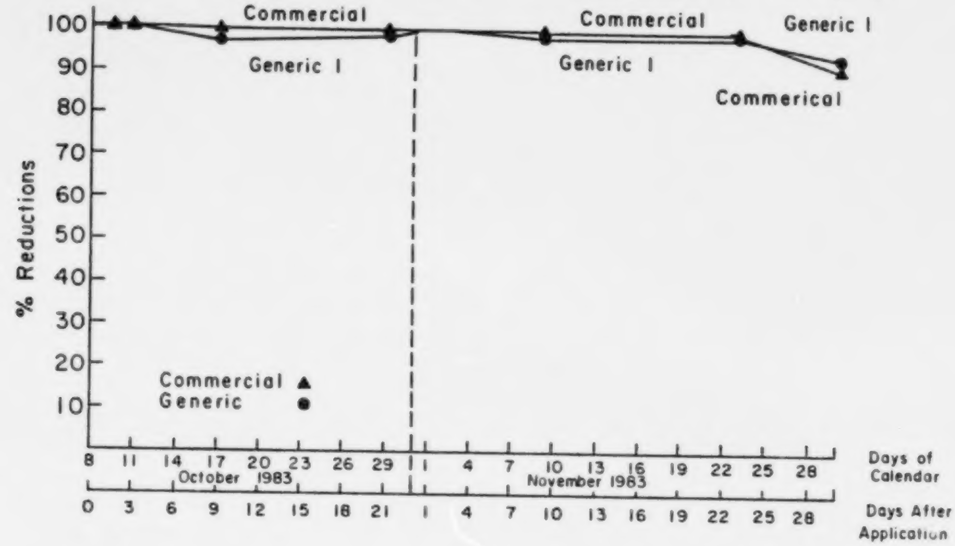


Figure 6 Generic I vs a Commercial Product - Fine Silt Control (0μm to 45μm)

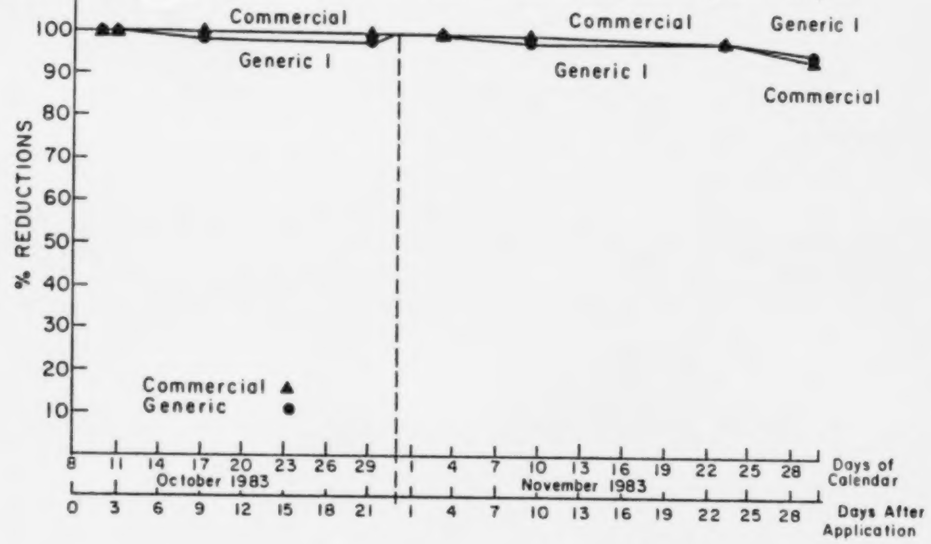
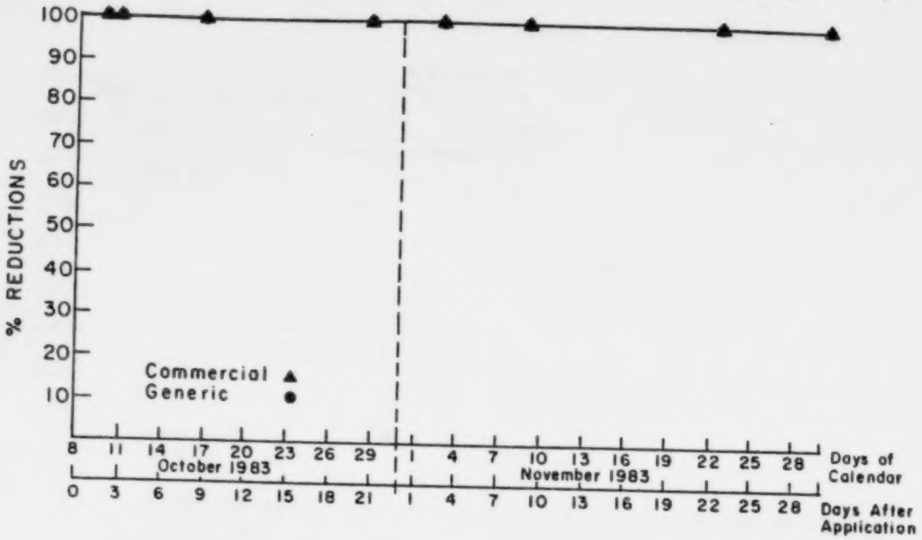


Figure 7 Generic I vs a Commercial Product - Respirable Silt Control (0μm to 10μm)



EMISSION FACTOR SUMMARY

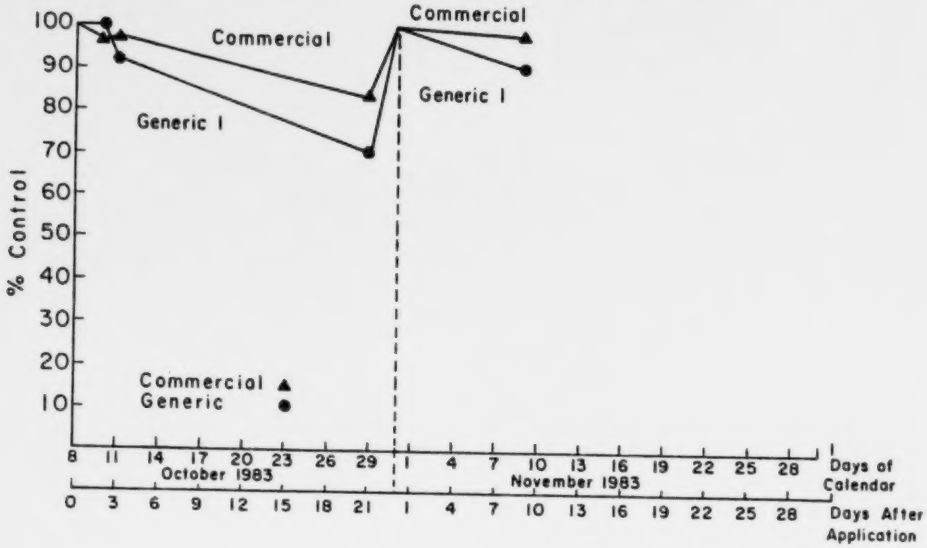
Table 5 presents a summary of emission factors for the two chemicals. As can be seen from inspection of the table, the commercial product performed somewhat better than Generic 1. These results are plotted in Figure 8.

TABLE 5. SUMMARY OF EMISSION FACTORS DETERMINED DURING THE AISI GENERIC DUST SUPPRESSION TESTING PROGRAM, SEPTEMBER - NOVEMBER, 1983

Date	Chemical	Days After Treatment	Emission Factor*	% Control
10/2-10/3	Uncontrolled	Before	5.99	0
10/8	Generic 1	Application	----	100.0
	Commercial	Application	----	100.0
10/10	Generic 1	3	0.03	99.5
	Commercial	3	0.23	96.2
10/11	Generic 1	4	0.51	91.5
	Commercial	4	0.18	97.0
10/29	Generic 1	21	1.70	71.6
	Commercial	21	0.98	83.6
11/1	Generic 1	Reapplication	----	100.0
	Commercial	Reapplication	----	100.0
11/9	Generic 1	9	0.54	91.0
	Commercial	9	0.10	98.3

*Uncontrolled factor based on 9 tests, controlled factor based on 2 tests, where possible.

Figure 8 Emission Factors - Generic 1 vs a Commercial Product



Comparison of the general slope of the curves shown in Figure 8 with the surface loading curves shown for total aggregate, total silt, and fine silt (Figures 4 to 6) demonstrate a correlation between surface loading and airborne particulate. That is, when surface loading increases, airborne particulate also increases. Therefore, it can be assumed from the graphs that although the Generic 1 formulation did not perform quite as well during the first exposure period, it should reduce airborne particulate somewhat more effectively than the commercial product by the end of the second application period. This improvement in performance would be a direct result of the more effective control of surface aggregate by Generic 1 vs. the commercial product as observed on November 30, 1983 (see Figures 4 to 6). This assumption is unconfirmed since weather conditions precluded the sampling of airborne particulate via exposure profiling.

The apparent, somewhat poorer performance based on emission factors of Generic 1 during the study should be considered with some caution. Originally, the study had been designed so that traffic could not enter the iron yard's main gate (see Figure 1). This greatly simplified the test.

Unfortunately, this gate had to be opened to traffic shortly after the chemicals were initially applied due to a major increase in Shenango's work load. This caused a significant abrasion and track-in problem to develop at the profiler sampling point of the Generic 1 test section. Each day the problem became steadily worse as traffic made the turn into the yard through this gate. This situation definitely caused an increase in airborne particulate at the Generic 1 profiler site. Quantitative estimates for this interference, however, could not be accurately determined.

COST/BENEFIT ANALYSIS

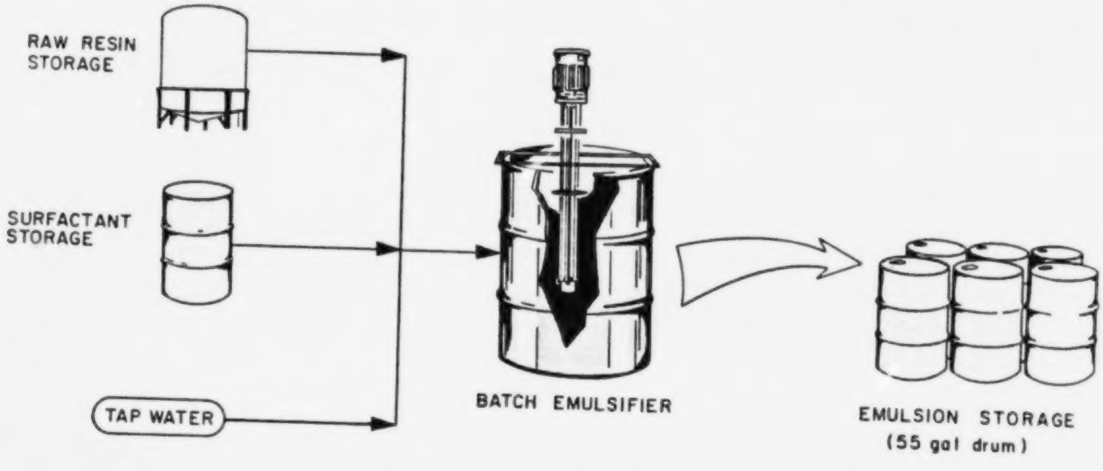
Iron and steel plants have varying suppressant quantity requirements. It was estimated that most suppressant users required between 12,000 and 250,000 gallons of concentrate annually. Because of this wide range of production needs, one type of process would not be appropriate for all iron and steel plants. Therefore, two separate processes have been designed (see Figures 9 and 10). Each process was designed to operate within a different capacity range. It was found to be important to match the capacity of the production process to the needs of each company so that maximum savings could be realized.

To determine the cost feasibility of on-site suppressant production at iron or steel plants, all costs associated with production must be accurately estimated. The following cost/benefit analysis is a definitive cost estimation comprising detailed data on individual equipment unit costs and installation costs.

Manufacturer's listed capital costs and installation costs were used whenever possible. In other cases, Guthrie's method(2) of capital cost estimation was used.

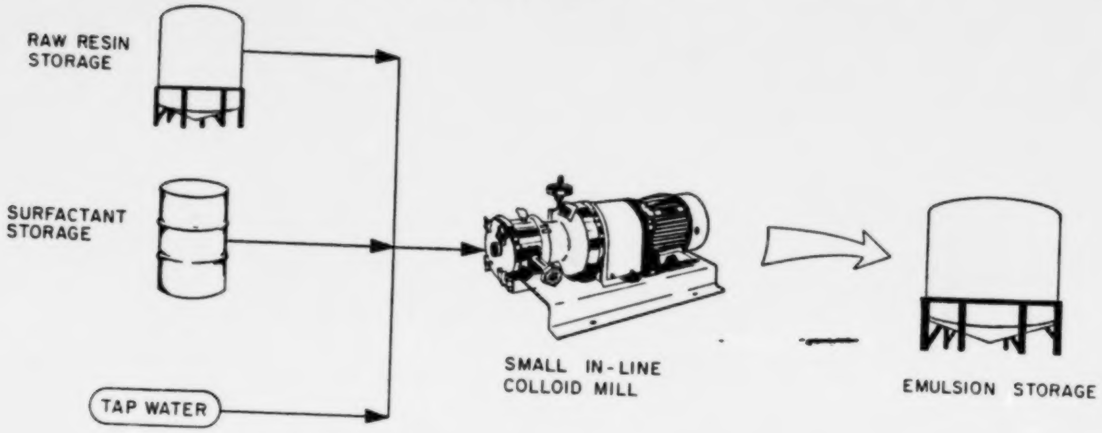
The total capital costs for both the small batch and the mid-size continuous processes were estimated in module form for each equipment unit.

Figure 9 Process Flowsheet for the Small-Scale* Production of Generic Dust Suppressant



* Production Capacity: 55 gal./batch (< 12000 gal. annual)

Figure 10 Process Flowsheet for the Continuous* Production of Generic Dust Suppressant



*Production Capacity: 160 gal/hr. continuous (12,000-425,000 gal. annual)

For the small batch process, the cost of purchasing and installing the resin storage tank and the emulsifier unit were estimated in separate modules and then combined for the total process cost. For the mid-size continuous process, the total installed cost of the resin storage tank, colloid mill, and product storage tank were combined to find the total process cost. Production costs were estimated from the base costs shown in Table 6.

TABLE 6. ECONOMIC DATA ESTIMATES FOR MID-1985

Labor Wage Rate.	$23.00/hr.
Steam (15 psi)	$11.00/M lb.
Process Water.	$0.005/gal.
Electricity.	$0.10/kwh

CONCLUSIONS

The major results and conclusions of the study are as follows:

GENERAL

1) Oil-resins are available, both locally and probably elsewhere, that can be used to formulate generic suppressants.

2) Generic oil-resin emulsions can be manufactured with relative ease, provided the ingredients (surfactant, stabilizer, resin) are properly matched and proportions used are correctly determined in the laboratory and field.

3) A generic oil-resin based dust suppressant was successfully formulated and it was found to be highly efficient in controlling dust from an unpaved road. Time lapse photography dramatically supported this conclusion.

4) The Generic 1 emulsion tested showed excellent properties with regard to dilution and roadway application behavior.

5) Optimal dilution ratios and application rates for the generic suppressant were determined via the field study.

FIELD TEST

Surface Aggregate

The analyses of surface aggregate show that:

1) The commercial product was somewhat more effective than Generic 1 in controlling total surface aggregate, total silt (0-75 μm), and fine silt (0-45 μm) during the first exposure period.

2) Second exposure period data show an increase in the efficiency of Generic 1 as compared to the commercial product for controlling total surface aggregate, total silt, and fine silt. This indicates that multiple applications of Generic 1 tend to increase its longevity and improve its emission control performance.

3) Generic 1 and the commercial product were comparable during both exposure periods for controlling respirable silt (0-10 μm).

Exposure Profiling

1) During the first exposure period the commercial product performed somewhat better than Generic 1 for controlling airborne emissions. This data, however, should be considered with some caution in view of the significant vehicle abrasion/track-in problem that had developed due to the change in traffic patterns after the test had begun. This situation definitely caused an increase in airborne particulate at the Generic 1 profiler site. Quantitative estimates for this interference, however, could not be accurately determined.

2) Based on the improved performance as measured by surface aggregate and silt loading of Generic 1 during the second exposure period, it is estimated that the emission factors for Generic 1 are comparable to those of the commercial product.

SUPPRESSANT PRODUCTION COST/BENEFIT SUMMARY

Iron and steel plants have varying suppressant quantity requirements. Therefore, a suppressant fabrication process should be matched to the individual company's requirements in order to maximize savings.

The Small Batch Process

1) The small batch process was designed to produce between 10,000 and

12,000 gallons of suppressant annually. The capital cost required for equipment purchase and installation for the small batch process was estimated to be $9,100.

2) Using the small batch process, an iron or steel plant requiring 12,000 gallons of suppressant annually could save an estimated 31 percent of the purchase price of the commercial product (priced at $1.65/gallon) by producing a generic suppressant on-site.

3) The payout time is the amount of time required to recover capital expenditures if all savings are devoted to this purpose. The payout time for the small batch process producing 12,000 gallons of suppressant annually was a favorable 18 months.

The Mid-Size Continuous Process

1) The mid-size process is an efficient process designed to manufacture between 12,000 and 240,000 gallons of suppressant annually. The capital cost required for equipment purchase and installation of the mid-size continuous process was estimated to be $29,000.

2) Using the mid-size continuous process, an iron or steel plant requiring 150,000 gallons of suppressant annually could save an estimated 48 percent of the purchase price of the commercial product (at $1.65/gallon) by producing a generic suppressant on-site. Production of quantities greater than 150,000 gallons annually would yield an even greater savings.

3) The payout time for the mid-size continuous process manufacturing 150,000 gallons of suppressant annually was a very favorable 2.9 months.

ACKNOWLEDGEMENT

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(2) Capital Cost Estimating. Guthrie, K. M. Chemical Engineering, 76(6). p. 114. 1969.

QUANTIFICATION OF ROADWAY FUGITIVE DUST AT A LARGE MIDWESTERN STEEL MILL

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ABSTRACT

The purpose of this research was to quantify roadway emissions at the Gary Works of U.S. Steel. This steel mill has over 80 miles of roads within its boundaries. The research took place in two phases. First, a field survey consisting of 515 vehicle counts and 165 roadway silt/surface loading samples was completed. Also, all regular vehicle movements (e.g., transport of tar from the coke plant to the blast furnace, hot roll shipments) were identified by origin, destination, trip path, and vehicle type. These 200 movements were each quantifiably related to a scaling parameter of plant production (e.g., coke production, sinter production) reported in the plant's Daily Report of Operation. The second phase consisted of the design and application of a computer program that assigned the 200 regular vehicle movements for the plant road system. The computer-assigned vehicle trips were calibrated against the 515 vehicle counts taken during the field survey. After calibration, the computer output for each roadway section (approximately 300) listed plant area, road classification, measured silt and surface loading, length, calculated vehicle miles traveled/shift by vehicle type, calculated average emission rate, and calculated emissions/shift. When plant operations change, as reflected in the Daily Report of Operations, all vehicle miles traveled and emission data can be adjusted accordingly.

INTRODUCTION

The quantification of roadway fugitive particulate emissions from industrial plants requires the input of various parameters, one of which is traffic volumes for each street segment. These data are difficult to obtain. For example, the U.S. Steel Gary Works contains approximately 80 miles of road in a complicated street network with over 200 intersections, nine gates, and 11 external parking lots. Counting each street segment by vehicle type, weekday, Saturday, Sunday, and three shifts is, for all practical purposes, impossible. A method was needed that would allow the extrapolation of a subset of counts to all roadway segments.

In addition, the steel industry in general is rapidly changing; efforts are constantly being made to optimize production and employment. The Gary Works is no exception. Several operations have been eliminated or reduced in scope, and corresponding reductions in employment and vehicular traffic have resulted. Because further production changes will occur, the method for quantifying traffic should also permit adjusting traffic levels to changing levels and methods of production.

The method developed to meet these requirements was a computerized program that related all vehicle movements to plant operations reported in the mill's Daily Report of Operations (DRO). This program required the identification of approximately 200 regular truck movements, called vectors (e.g., transporting tar from the coke plant to the blast furnace, moving coal from shaker to storage, hot roll shipments). The vectors were tied to scaling parameters of plant production reported in the DRO, such as coke production, sinter production, ingot production, etc. Each vector was quantifiably related to a scaling parameter by use of a scaling factor. For example, for the vector describing Hot Strip Mill Scale to Blending Area, it was determined that 0.0005 trip/ton of hot strip mill production were made by a rear-dump truck with a 25-ton capacity on weekday second shift.

The computer predicted truck trips by shift and day of the week on each road segment or link by use of the vectors, scaling parameters, and scaling units. These predicted values were compared with 515 actual vehicle counts made during the field survey. The vector analysis was then calibrated to the vehicle counts on a vehicle-specific, link-specific basis.

DATA COLLECTION

PRESURVEY

The presurvey involved gathering information on or for the following subjects.

Vector/Scaling Parameter Analysis

Implementation of the vector/scaling parameter analysis required a detailed knowledge of all plant functions, including their locations and interrelationships. Extensive interviews were conducted with plant personnel and plant contractors. For many operations, material flow diagrams were developed that identified material movement locations, quantities, truck sizes, and number of trips. Material balances were prepared to verify the reasonableness of certain vector densities or to calculate densities where no data were available. For example, pellet fines from the screening operation were calculated to determine the number of trips for hauling fines to the sinter plant. Many of the haul routes were verified by traffic counts made during the presurvey.

Road Classification

Almost all paved roads in the plant have unpaved shoulders. Surface loading and silt, however, vary widely throughout the plant depending on spillage, type of material being hauled over the road, particle fallout from the air, and wind erosion from adjacent areas. Because their large numbers prevented sampling every individual road link in the plant, a decision was made to classify all roads by type according to paved/unpaved, type of material hauled over the road, adjacent wind erosion, and the amount of surface loading as determined by visual examination (medium, heavy, very heavy). Based on these criteria, 17 paved road and 16 unpaved road types were delineated. All roads in the plant were assigned to one of the 33 categories. Two to 15 road samples were taken at random locations along a portion of the roads in each category, and these measurements were then applied to all roads in that category.

Count Locations

Count locations were determined after driving the plant roads several times, consulting with plant personnel, and examining a map of the plant showing all roads and all building locations by name. Approximately 50 intersections, 6 external gates, and 11 external parking lots were identified as count locations after a review of the locations with the plant personnel.

Vehicle Types

A plant inventory identifying all plant vehicles by type and weight was obtained from plant personnel. These data were supplemented by observations of nonplant vehicles (product haulers, vendors, contractors) traveling within the plant. A preliminary vehicle type list was compiled and reviewed with plant personnel for accuracy.

Miscellaneous Data

A number of additional miscellaneous data items were also collected. These included:

(1) Gate passes showing the origin and destination of vehicles coming into the plant.
(2) Employee travel/month from expense reports.
(3) Vendor passes.

(4) Aerial photographs and numerous maps.
(5) Copies of DRO's.
(6) Employment records.

FIELD SURVEY

Vehicle Counts

The result of the vehicle portion of the presurvey was a facility map marked with coded count locations and a daily schedule of required counts to be taken. Vehicle counts were taken at each coded intersection according to the daily schedule. Counts were also taken during off-shift periods and on weekends. For a given intersection, each road link was numbered from 1 to 6, depending on the number of links. For each counting period at an intersection, a safe location that permitted a good view of each link was selected. From this location, each vehicle crossing the intersection was counted and classified by type and by the origin and destination links used. Twenty different vehicle classifications were used during the counts. Each counting period lasted 30 minutes to 4 hours.

Counts were also taken at six external plant gates and at hourly employee external parking lots. At the external gates, counts were 3 to 4 hours in duration over a shift change. A total of 11 parking lots were counted several times to determine the number of cars actually parking in each lot.

Road Surface Samples

The predictive emission factor equations require data on the dust-emitting aggregate materials being disturbed by the action of wind or machinery. For unpaved roads, the silt content is required. For paved roads, silt content and surface loading data are required. The sampling and analysis procedures used to acquire these data were structured identically as laid out in American Society for Testing and Materials (ASTM) Standards when practicable. When this was not possible, an attempt was made to develop the procedure in a manner consistent with the intent of the majority of pertinent ASTM Standards.

ANALYSIS PROCEDURES

VEHICLES

Extrapolation of Short-Term Counts

When the data from all of the counts had been compiled, the next step was to convert the short-term counts to equivalent counts by shift. Some of the vehicle classifications in the preliminary vehicle list were combined to form 12 new categories, which represent the final vehicle classifications for the remaining analyses. These final classifications are shown in Table 1.

The next step was to compile all of the counts from the field data forms into the new categories by road link. During this process, the individual

TABLE 1. FINAL VEHICLE CLASSIFICATIONS

Vehicle Category	Work Schedule, min/shift			Weight, tons*	Wheels
	1	2	3		
1. Flatbed-over the road	0	450	120	24.5	18
2. Flatbed-lowboy, coil	400	400	400	57.0	20
3. Scow	400	400	400	25.6	6
4. Trailer-dump	400	400	400	22.5	20
5. Straddle carrier	400	400	400	12.5	4
6. Tanker	0	450	120	25.8	18
7. Service vehicle, 10 to 15 tons	400	400	400	14.3	10
8. Utility	400	400	400	7.6	6
9. Passenger/pickup	420	420	420	2.9	4
10. Bus	180	180	180	8.8	6
11. Miscellaneous (< 5 tons)	400	400	400	2.0	4
12. Miscellaneous (> 5 tons)	400	400	400	15.0	9

*Represents 50/50 percent split of loaded and unloaded vehicles. Vehicle weight data obtained from plant vehicle inventory.

TABLE 1. FINAL VEHICLE CLASSIFICATIONS

Vehicle Category	Work Schedule, min/shift 1	2	3	Weight, tons*	Wheels
1. Flatbed-over the road	0	450	120	24.5	18
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4. Trailer-dump	400	400	400	22.5	20
5. Straddle carrier	400	400	400	12.5	4
6. Tanker	0	450	120	25.8	18
7. Service vehicle, 10 to 15 tons	400	400	400	14.3	10
8. Utility	400	400	400	7.6	6
9. Passenger/pickup	420	420	420	2.9	4
10. Bus	180	180	180	8.8	6
11. Miscellaneous (< 5 tons)	400	400	400	2.0	4
12. Miscellaneous (> 5 tons)	400	400	400	15.0	9

*Represents 50/50 percent split of loaded and unloaded vehicles. Vehicle weight data obtained from plant vehicle inventory.

counts for each intersection were further subdivided into weekday, Saturday, and Sunday counts.

The following general equation was used to convert a single short-term count into an equivalent shift count:

$$\text{Equivalent Shift count} = \frac{\text{Short-term count}}{\text{Time of count}} \times \text{Shift work schedule} \qquad \text{(Eq. 1)}$$

For each type of vehicle, a work schedule was defined for each shift, as shown in Table 1. The work schedules had to be assumed for most of the vehicle types; actual schedules were available only in the case of two specific bus routes.

Finally, based on the values in Table 1, the actual vehicle counts, and the time of each count, Equation 1 was applied to the field data for each vehicle category to obtain the equivalent shift count by shift and weekday, Saturday, or Sunday. In general, Equation 1 was applied directly to the short-term counts by vehicle category. When more than one count was taken for a specific shift and day of the week, however, the total vehicle count and total counting time from the multiple counts were calculated for each vehicle category before Equation 1 was applied.

When all the calculations were completed, the counts for each vehicle type were plotted by road link on a separate map. This resulted in 12 separate maps of the facility, one for each vehicle category.

Calibration of Vector/Scaling Parameter Analysis to Vehicle Counts

Truck Traffic--

As mentioned previously, the truck traffic was predicted by a vector/-scaling parameter procedure. The scaling parameters used are shown in Table 2. The model-predicted truck traffic from the vector/scaling parameter analysis required calibration to match the ground counts. Discrepancies between the model-predicted values and the counts can be attributed to one or more of the following factors:

(1) Inaccurate scaling factor.
(2) Wrong trip path from origin to destination.
(3) Improper vehicle type in vector.
(4) Errors in vehicle count, consisting of improper extrapolation of ground counts, counts taken when a particular activity was not being performed, and counts taken during atypical operational patterns.

The model-predicted values by vehicle type and shift were plotted on a map along with corresponding expanded ground counts, and the values were compared. When differences were found, the four sources of possible error were examined. This consisted of recontacting various plant personnel to verify scaling factors, trip paths, vehicle operations, and plant operations during the survey period. The calibration was performed iteratively, and a total of three model runs were required to obtain acceptable calibration results.

TABLE 2. SCALING PARAMETER VALUES USED IN ANALYSIS

Production	Scaling parameter value (21 Shifts)
Coke	42,423
Blast furnace 13	55,646
Total raw steel	100,800
Blast furnaces 4 and 6	34,423
Galvanizing lines	4,075
Ingot production	61,050
BOP ingots, cast slabs	41,854
Sintering	44,027
Plate mill	4,715
Bar and structural	2,033
Primary mills	51,365
Hot strip mill	62,685
Hot metal	90,069
Tin cold reduction	7,584
Electro-galvanizing	8,964
Picklers	52,472

Autos, Light-Duty Trucks, and Utility Vehicles--

A significant amount of traffic in the plant throughout the day consists of automobiles and light-duty trucks. This traffic includes supervisory personnel traveling from place to place, maintenance vehicles, construction personnel, nonroutine deliveries, etc. A portion of it involves plant personnel using private automobiles. On almost all individual road links, automobiles and light-duty trucks account for over one-half of the vehicle count. Because the majority of these trips are nonroutine and do not follow regular patterns, a vector/scaling parameter approach was not feasible; the auto, light-duty truck, and utility vehicle traffic was therefore input directly.

Adequate counts were available to assign weekday second-shift values to each link. Although counts were not available for many links on off-shifts, 266 counts were taken during the eight off-shift periods. To calculate auto and light-duty truck traffic for off-shift periods for each of eight areas in the plant (the same areas used for exposed-area sampling), ratios of weekday second-shift traffic to each of the other eight shift periods were calculated. This resulted in eight sets of eight distribution factors to assign auto and light-duty truck traffic.

The same procedure was used to develop an additional eight sets of eight distribution factors for utility vehicles. This was necessary because the counts indicated that the shift distributions of the two vehicle categories were significantly different.

VECTOR/SCALING PARAMETER MODEL DESCRIPTION

As mentioned in the Introduction, the Vector/Scaling Parameter Model was developed for this specific application. The program contains two basic data files, a link data file, and a vector file, which are summarized in Table 3.

TABLE 3. MODEL DATA FILE INDEX

Link data file	Vector data file
Link identifier	Vector number
Area	Description
Category	Origin and destination centroid
Silt, percent	Vehicle type
Surface loading, lb/mile	Scaling parameter and value
Average speed, mph	Scaling factor
I-Factor	Shift allocation factor
Number of lanes	Links used by vector
Link length, miles	
Auto and utility vehicle shift allocation factors	

The conceptual procedure for the model is as follows:

(1) Read link data file.
(2) Print link description.
(3) For link 000/000, identify all vectors using link.
(4) Obtain trips/shift by vehicle type from each vector.
(5) Combine trips from all vectors and print number of vehicles by shift. Sum columns for vehicles/shift.
(6) Multiply number of trips/shift by link length to obtain vehicle miles traveled (VMT)/shift. Print. Multiply weekday values by 250 (10 holidays assumed), and Saturday and Sunday values by 52 to obtain VMT/year. Print.
(7) Calculate emission rate for each vehicle type using vehicle characteristics and unique link characteristics (silt, surface loading, speed, I-Factor). EPA emission factors are used. Print.
(8) Calculate weighted average emission rate. Print.
(9) Multiply average emission rate by VMT/shift to obtain TSP, tons/shift. Print.
(10) Multiply values to obtain total suspended particulates (TSP) in tons/year. Print.

A link summary printout is shown in Figure 1.

CALCULATION OF EMISSIONS

Emissions for vehicular traffic were calculated by using EPA Emission Factors (1). For unpaved roads, the equation used was:

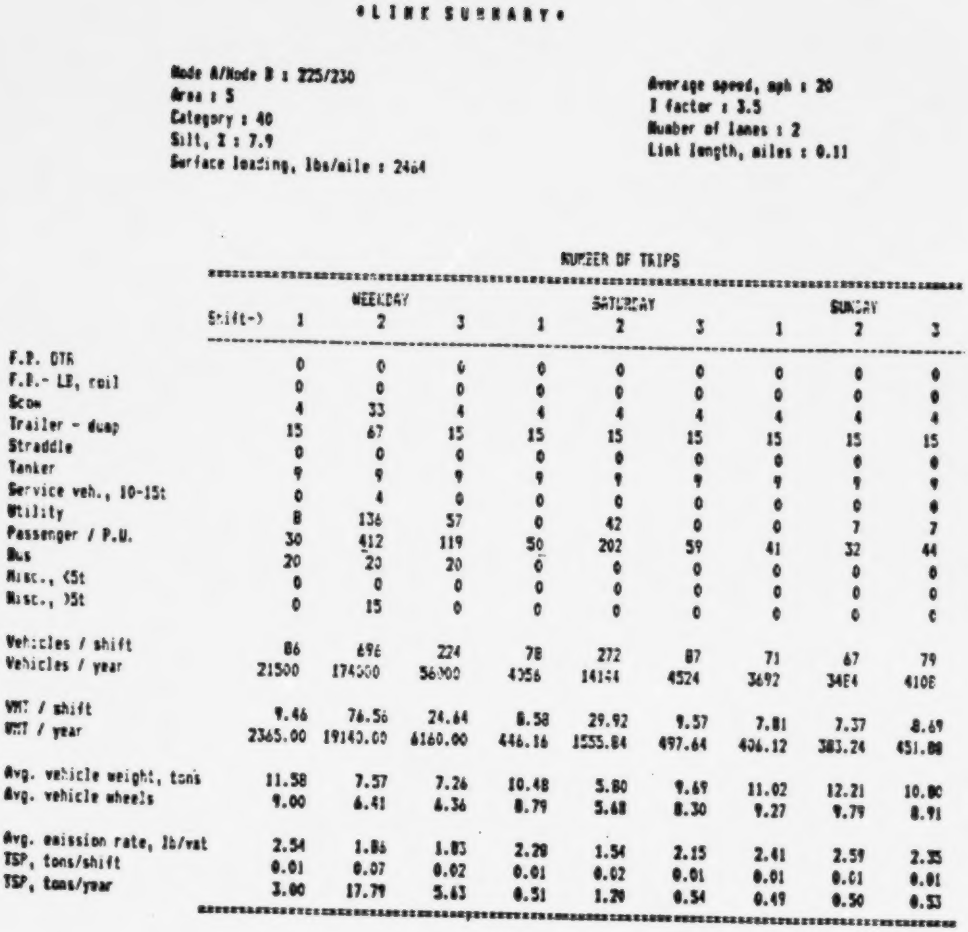
$$E = k(5.9) \quad \frac{s}{12} \quad \frac{S}{30} \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{d}{365} \qquad \text{(Eq. 2)}$$

where
E = Emissions, lb of $\leq$ 30-micrometer particulate
k = particle size multiplier (dimensionless) = 0.80
s = silt content of road surface material, %
S = mean vehicle speed, mph
W = mean vehicle weight, tons
w = mean number of wheels
d = number of days with less than 0.254 mm (0.01 in.) of rainfall per year = 222

For paved roads the following equation was used:

$$E = k(0.090)\ I \quad \frac{4}{n} \quad \frac{s}{10} \quad \frac{L}{1,000} \left(\frac{W}{3}\right)^{0.7} \qquad \text{(Eq. 3)}$$

where
E = Emissions, lb of $\leq$ 30 micrometer particulate
I = industrial augmentation factor (dimensionless)
n = number of traffic lanes
s = surface material silt content, %
L = surface dust loading, lb/mile
W = average vehicle weight, tons



```
                              *LINK SUMMARY*

              Node A/Node B : 225/230                       Average speed, mph : 20
              Area : 5                                      I factor : 3.5
              Category : 40                                 Number of lanes : 2
              Silt, % : 7.9                                 Link length, miles : 0.11
              Surface loading, lbs/mile : 2464


                                                   NUMBER OF TRIPS
                      ================================================================================
                                      WEEKDAY                    SATURDAY                   SUNDAY
                      Shift->     1       2       3         1       2       3         1       2       3
                      --------------------------------------------------------------------------------
F.P. OTR                          0       0       0         0       0       0         0       0       0
F.P.- LB, coil                    0       0       0         0       0       0         0       0       0
Scow                              4      33       4         4       4       4         4       4       4
Trailer - dump                   15      67      15        15      15      15        15      15      15
Straddle                          0       0       0         0       0       0         0       0       0
Tanker                            9       9       9         9       9       9         9       9       9
Service veh., 10-15t              0       4       0         0       0       0         0       0       0
Utility                           8     136      57         0      42       0         0       7       7
Passenger / P.U.                 30     412     119        50     202      59        41      32      44
Bus                              20      20      20         0       0       0         0       0       0
Misc., <5t                        0       0       0         0       0       0         0       0       0
Misc., >5t                        0      15       0         0       0       0         0       0       0

Vehicles / shift                 86     696     224        78     272      87        71      67      79
Vehicles / year               21500  174000   56000      4056   14144    4524      3692    3484    4108

VMT / shift                    9.46   76.56   24.64      8.58   29.92    9.57      7.81    7.37    8.69
VMT / year                  2365.00 19140.00 6160.00   446.16 1555.84  497.64    406.12  383.24  451.88

Avg. vehicle weight, tons     11.58    7.57    7.26     10.48    5.80    9.69     11.02   12.21   10.80
Avg. vehicle wheels            9.00    6.41    6.36      8.79    5.68    8.30      9.27    9.79    8.91

Avg. emission rate, lb/vmt     2.54    1.86    1.83      2.28    1.54    2.15      2.41    2.59    2.35
TSP, tons/shift                0.01    0.07    0.02      0.01    0.02    0.01      0.01    0.01    0.01
TSP, tons/year                 3.00   17.79    5.63      0.51    1.29    0.54      0.49    0.50    0.53
                    ================================================================================
```

Figure 1. Link summary printout.

It should be noted that the paved road emission factor contains no term for dry days (d) as the unpaved road emission factor does. This is arguable. The EPA suggests dry days not be used with paved roads because rainfall increases track-on from shoulders and unpaved roads and thus increases emissions. Conversely, the I-Factor of 1.0 for roads with curbs versus 3.5 for roads with unpaved shoulders already increases emissions by a multiplier of 3.5 times. No field testing has been done to validate or invalidate the use of the dry days term with paved roads.

RESULTS

Paved road emissions for the entire plant for a single weekday, Saturday, and Sunday were calculated to be 50.8, 16.9, and 12.0 tons/day, respectively. Corresponding values for unpaved roads are 8.0, 4.9, and 3.8 tons/day, respectively. Weekday second shift accounted for 68 percent of weekly emissions. The average emission rates for paved and unpaved roads were calculated to be 2.1 and 6.9 lb/VMT. A dust control program incorporating paved road sweeping/flushing, and unpaved road dust suppressants was in place at the plant during the time of the survey.

Comparative EPA-sponsored field testing is limited. In two tests at a steel plant on a paved road without curbs, the average emission rate was 2.1 lb/VMT (2). Uncontrolled emissions from unpaved (crushed-slag) roads were measured in nine tests at an average of 6.8 lb/VMT (3). These values are remarkably close to the values calculated as a result of this study.

Beyond the use of the data for an emissions inventory, the calibrated Vector/Scaling Parameter Model has other potential uses as a planning and estimating tool. First, as production levels change in the plant over time, the DRO values can be input to the model to predict new roadway emission levels for a revised emission inventory. Secondly, the model could be very useful at optimizing emission control expenditures. The emissions by link data very clearly show the major roadway emission locations throughout the plant. Conversely, these data also indicate where control dollars are being spent on roadways with little traffic. By varying control expenditures on specific road segments, the model can predict changing emission levels. Because the data also show emission levels by the vehicle type that may be associated with a specific activity, causes for high surface loadings can sometimes be identified or routes certain vehicle types take can be changed to cleaner roads to reduce emissions. Thus, the calibrated Vector/Scaling Parameter Model is not only useful for producing an initial emission inventory, it can also be used to revise emission inventories in future years and to optimize roadway dust-control expenditures.

Because the work described in this paper was not funded by the U.S. Environmental Protection Agency, the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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INHALABLE PARTICULATE (PM10) SAMPLING PROGRAM TEST RESULTS IN IRON AND STEEL PRODUCTION AND COKE MANUFACTURING SOURCE CATEGORIES

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ABSTRACT

EPA is nearing completion of a major program to develop PM10 emission factors, where PM10 is defined as airborne particles of $\leq$10 um aerodynamic equivalent diameter. This paper summarizes efforts to date and presents final results for the iron and steel production and coke manufacturing source categories. Combining data found in the literature with data from field tests funded by this program, it was possible to develop particle size emission factors (including PM10) for the following iron and steel sources: sinter windbox, sinter discharge, blast furnace cast house. BOF hot metal charge, BOF refining, BOF tap, QBOP hot metal charge, QBOP refining, open hearth furnace, electric arc furnace, and hot metal desulfurization (CaC_2). For coke manufacturing, particle size emission factors are presented for: wet coal charging, coal preheater, pushing, quenching, and combustion stack. In most cases, both uncontrolled and controlled particle size emission factors are presented; notable exceptions are the blast furnace cast house (uncontrolled only) and BOF and QBOP refining (controlled only).

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INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is required, under the amended Clean Air Act of 1977, to review the scientific basis for the total suspended particulate ambient air quality standard. As a result of this review, EPA announced in the March 20, 1984, Federal Register (Vol. 49, No. 55, pp. 10435-10462) its intent to promulgate a primary standard based on particles of ≤10 um aerodynamic equivalent diameter (PM10) and proposed a range of values under consideration.

EPA initiated an extensive program in 1979 to compile and review existing particle size source data and, where necessary, conduct field sampling programs from which reliable PM10 emission factors could then be determined. A major part of this effort has been directed toward the steel industry, which includes both the iron and steel and most of the coke manufacturing source categories. This paper addresses the recently completed steel industry directed effort. Data analysis procedures are discussed, some of the major problems encountered and their solutions are described, and the final particle size emission factors are presented.

DISCUSSION

The methodology followed for determining which emission sources would be picked for field tests has been described in detail in previous publications.(1,2) Suffice it to say here that an aggregate list of iron and steel and coke manufacturing sources was constructed and ranked by total annual particulate emissions. Sources were selected for field testing starting at the top of the list. Some minor midpoint adjustments were made as a result of particle size data subsequently found in the literature during the course of the project.(2) The final sources selected for testing are listed in Table 1. Of those picked, the full combustion BOF refining and the electric arc tests were repeatedly postponed due to low steel production levels at the plants selected. These tests were ultimately cancelled.

Particle size and total particulate emission sampling methodologies have also been described in detail elsewhere.(1,2) In all but three instances, an Andersen Mark III cascade impactor with a precutter cyclone (Figure 1) was used for particle sizing ducted process source emissions. For the BOF hot metal charge and tap tests, the inhalable particulate (IP) dual-cyclone train (Figure 2) was used for sampling before the control device (baghouse). The Andersen heavy grain loading (HGL) train (Figure 3) was used to sample before the control device (baghouse) during the sinter discharge tests. In all cases, an EPA Method 5 train was used to obtain total particulate samples of process emissions. Emissions from vehicular traffic on roads were measured by the exposure profile technique(3) which uses an array of modified hivol samplers for total particulate measurement and the Sierra precutter cyclone/five-stage cascade impactor combination for particle sizing.

DATA ANALYSIS

For process source tests, the total particulate data analysis scheme followed the standard EPA Method 5 protocol.(4) Particle size data were analyzed by fitting a curve through the data points derived from the individual stage weights and stage cutpoints of the particle size device used. For the IP dual-cyclone train, the curve was fitted manually. The Andersen HGL data from the sinter discharge test were also curve-fitted manually. The Andersen Mark III data were reduced and analyzed using a computer program called the Particulate Data Reduction Entry system (PADRE)(5) which incorporates a spline-fit curve-fitting subroutine. PADRE also incorporates standard EPA Method 5 data reduction.

PADRE is an interactive program installed on EPA's mainframe computer which can be accessed via telephone using a portable terminal. Several advantages are derived by using PADRE. First, all data are reduced by the same procedure, one which reflects the ideas and recommendations of many "experts" in the particle sizing field. Second, PADRE calculates and reports the actual cut points of each impactor stage and the precutter cyclone. It then interpolates or extrapolates as necessary to give the cumulative mass at any set of standard cut points desired by the operator. Third, it allows the operator to input the calibration data for the specific cyclone/impactor or to select a generic calibration. Fourth, PADRE incorporates extensive data checks and displays warning messages alerting the operator to potential errors. Finally, PADRE incorporates a subroutine, COMPARE, which calculates the mean and standard deviation for any set of individual runs from a test. If the test includes particle size distribution measurements before and after a control device such as a baghouse, then PADRE will calculate the average inlet and outlet particle size distributions and the control efficiency as a function of user specified particle size ranges.

Tables 2-4 are examples of PADRE input and output for a single run and output for an entire test, respectively. Note the various messages (such as low stage weights and combining of certain stage weights) when successive stage cut points are too close together. In the latter case, the criterion is a ratio of 1.5 for successive stage cut points. If the ratio is less than 1.5, the higher cut point is ignored; the mass of both stages is assigned to the stage with the lower cut point.

Problems and Solutions - Several problems with data reduction arose during the course of the IP program. Following is a brief discussion of the three major problems and the approaches taken to solve them.

The precutter cyclone (Cyclone IX) designed and built for the IP program was intended to have a 15 um cut point D_{50} at the design conditions of 14.8 lpm and 150°C. A preliminary limited calibration indicated that these design criteria were met. Early in the field sampling program, several sampling runs were made at flowrates substantially below the range of this limited calibration. Extrapolating to these low flows was technically very weak. The decision was then made to recalibrate the cyclone over a wider range of conditions. After many long, tedious months the new calibration was completed. Surprise! The new calibration did not agree with the old one. After double and triple checking the data, it was determined that the old calibration was in error. As shown in Figure 4, the effect of the recalibration was to shift the cut point at design conditions downward from 15 um to 12.7 um. This new calibration was programmed into PADRE replacing the old values. Of course, this meant that all field test data had to be rerun.

The second problem concerned several shortcomings in PADRE. Typical of these was that it would not accept the cyclone (Andersen Mark III) configuration and it would not average several runs to yield a single size distribution for a test. In the first case, the solution was a relatively simple programming change; whereas, in the latter case, a new subroutine (COMPARE) had to be developed and verified.

The third problem encompasses the whole subject of open source fugitive dust measurement. Dust raised by vehicular traffic is the major open source in steel plants. Traditionally, EPA has utilized open source emission factors based on measurements made with the Midwest Research Institute (MRI) exposure profile technique.(3) In recent years, several other firms have mounted extensive open source field tests for other sponsors. Although all use techniques similar to MRI's, each differs from the others in detail. Not surprisingly, results obtained by these other firms have sometimes been in substantial disagreement with the results predicted by the equations in AP-42(6) which are based on MRI developed data. The resulting controversy cast a shadow of uncertainty over, in particular, the emission factors for vehicular traffic on paved and unpaved roads. To resolve the controversy, EPA initiated a project in July 1983 with the goals of (1) developing a technique for normalizing data obtained by the different firms to a common base and (2) specifying in detail a standard test method and analytical procedure for all future field work. Results of the work are expected to be published in about 6 months.

RESULTS

Particle size emission factors for iron and steel and coke manufacturing source categories reported herein are based on data obtained from the literature and data from field tests funded under EPA's IP program. A search of published and unpublished literature yielded 28 source tests in the iron and steel source category and 15 in the coke manufacturing source category which contained particle size test data. EPA's IP program added another 12 and 5 source tests, respectively. Tables 5 and 6 present the above broken down by individual source. A source test is defined here as a series of individual sampling runs at the same site which ultimately yield an emission factor. Tests before and after a control device at the same site are classified as two source tests since both controlled and uncontrolled emission factors will be reported in AP-42.

The aforementioned literature search also revealed the existence of more than 200 additional source tests containing total particulate data but no particle size data. A large majority of these data were not available for consideration in the 1980 AP-42 update of the iron and steel and coke manufacturing emission factors. EPA decided to review this extensive addition to the data base and, where appropriate, revise the total particulate emission factors simultaneous with the addition of the particle size emission factors.

The final results of nearly 5 years effort and the expenditure of about $750,000 are presented in Tables 7-10. Specifically, Table 7 gives the total particulate emission factors, and Table 8 contains the emission factors as a function of particle size for those sources for which data are available in the iron and steel source category. Tables 9 and 10 present the equivalent data for the coke manufacturing source category. The results presented in these tables are believed to be accurate and representative of the steel industry as a whole. However, one must realize that, for several sources, the final emission factor is based on one test at one site. The extent to which plant-to-plant variability for the same process affects particle size distribution is therefore not reflected in the result. There are sources in each source category for which no particulate size data are available. EPA is currently preparing generic emission factors for use in these instances. (Note: As of this writing (mid-October 1984) these data have not completed EPA review requirements. Although the chances are low, some changes may nevertheless be required prior to final publication. Readers should be careful in using these data at this time.)

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TABLE 1. SOURCES SELECTED FOR FIELD TESTS

- Iron and Steel
  - Sinter Discharge
  - Blast Furnace Cast House
    - Building Evacuation
    - Local Capture
  - Hot Metal Desulfurization
  - BOF Hot Metal Charge
  - BOF Tap
  - BOF Refining
    - Full Combustion[a]
    - Limited Combustion
  - QBOP Refining
  - Electric Arc Furnace[a]
    - Fugitives
    - Direct Shell Evacuation
  - Vehicular Traffic
- Coke Manufacturing
  - Coke Quenching
  - Coke Pushing

---

[a] These sources were never tested.

TABLE 2. PADRE PRINTOUT OF INPUT DATA FOR A SINGLE SAMPLING RUN

```
Enter the Run No., IRUN, or return to use current value

 ***Mass on stage                     1  is low
 ***Mass on stage                     3  is low
 ***Mass on stage                     4  is low
 ***Run date, 31180 before calibration date, 50581

Do you wish to list the data for run?  Enter Y or N
YY
Data for test by contractor RCM, at site Kais, on date 31080, Run No. 5
Test Comments      TCOMM = Kaiser/Fontana hot metal desulf. BH outlet tests
by Acurex
Particle Density (GM/CC):  RHO = 1.000

Run comments:           RCOMM = Run 16 Stack No. 2 (IDSUBS=177)
Date of Run:            JDATE = 31180  Ambient Pressure (IN H6)        PAMBNT=  28.86
Start Time:             ISTART = 1226  Stack Press WRT Ambient (IN H2O):DPSTK =  .60
Run Duration (Min):     Dur = 22.9 Stack Gas Velocity (FT/Sec):         VSTACK=  55.50
Run Type:               RTYPE = 0   Stack Temperature (DEG F):          TSTACK= 133.3
Carbon Dioxide:         CO2 = .0 Impactor Temperature (DEG F):          TIMP=   133.3
Carbon Monoxide:        CO =  .0 Max. Particle Diam. (MICRONS):         DMAX=    70.0
Nitrogen:               N2 =79.0 Cyclone Cut Point (MICRONS):           CYCL=     1.0
Oxygen:                 O2= 21.0 Nozzle Diameter (INCHES):              DNOZZ=     .123
Water Vapor:            H2O = 1.4 Nozzle Cut Point (MICRONS):           CUTNOZ=    .00
BACKUP Filter Used?  BF = Yes Large Particles on Filter?                FLARGE= NO
Flow Rate Determination:  Method = Method 5
Meter Temp (DEG F):  TMETER= 72.0  Initial Meter Reading (CF):          GMVOLI=  39.457
Meter Calib Factor:  CMETER= 1.0240  Final Meter Reading (CF):          GMVOLF=  46.157
ORIFICE Press ("H2O): DPORIF= .2  Volume of Water Collected (ML):       VOLH2O=    .00
Impactor Type:          IMPNAM=Andersen  Impactor Flow Rate (ACFM):     FLOW=      .339
Impactor Model:         IMPMOD=Mark 3
  IMP. Plate set ID: IPLATE=   0 Substrates ID:                         IDSUBS=     177
  IMP. Stages Used NS=  8 DESCR=Filter
NO. Jets       Diam.       CUMDP       CALIB        CYCLONE        .320 MG
  264         .1638       .0000       .3050        Stage 1        .001
  264         .1253       .0000       .4030        Stage 2        .130
  264         .0948       .0000       .4100        Stage 3        .090
  264         .0759       .0000       .3850        Stage 4        .010
  264         .0533       .0000       .3690        Stage 5        .350
  264         .0343       .1760       .3600        Stage 6        .630
  264         .0254       .2940       .3620        Stage 7        .270
  156         .0254      1.0000       .2740        Stage 8        .180

Impactor DP scaling Factor 1.287                   FILTER         .230 MG
```

TABLE 3. PADRE PRINTOUT OF RESULTS FOR A SINGLE SAMPLING RUN

```
Particulate Data Reduction and Entry System        10/01/84         16:04:55
Data for test by Contractor RCM, at site KAIS, on date 31080, Run No. 5
  ***Cyclone IX cut point Calculated  11.321169
Sampling at 121.5% of Isokinetic rate
Want to see results using classical (STOKES) def. of DIAM.?  Enter Y or N
N
  ***Linear Interpolation used between      5.3425305      7.9873265
Want to see results using the TGLD Def. of AERO. Diam.?  Enter Y or N
Y

Run 16 Stack No. 2 (IDSUBS=177)
Total Mass  4.4011-003   5.1748-003   1.0071+001    1.1842+001    DMAX=70.0
            GR/ACF       GR/DNCF      MG/ACM        MG/DNCM        MICRONS

 STAGE     MASS      MASS      CUM. MASS      D50        GEO.     MEAN DM/DLOGD    DN/DLOGD
          (MG)   (MG/DNCM)  (MG/DNCM)    (MICRONS)  (MICRONS)   (MG/DNCM)      (NO/DNCM)
CYCLONE    .32       1.71        10.13      11.32      28.15       2.17+000       1.85+005
   1       .00        .01        10.12      13.56      12.39      -6.83-002      -6.86+004
   2       .13        .70         9.43      11.98      12.74       1.29+001       1.19+007
   3       .09        .48         8.94       7.99       9.78       2.74+000       5.59+006
   4       .01        .05         8.89       5.34       6.53       3.06-001       2.10+006
   5       .35       1.87         7.02       2.97       3.99       7.36+000       2.22+008
   6       .63       3.37         3.64       1.45       2.08       1.08+001       2.31+009
   7       .27       1.45         2.20        .90       1.14       6.94+000       8.89+009
   8       .18        .96         1.23        .49        .66       3.62+000       2.39+010
FILTER     .23       1.23                                .34       4.09+000       1.92+011

  ***Cut Points for Stages 0  1 are similar or inverted
       Measured Data for Stage,  1 with D50=   13.56 Omitted From Interpolation
  ***Cut Points for Stages 1  2 are similar or inverted
       Measured Data for Stage,  2 with D50=   11.98 Omitted From Interpolation
  ***Linear Interpolation Used Between  5.3425305      7.9873265
Interpolated to Std. Intervals:  (Values at Diam. Marked with * are Extrapolated)
                                   1.50        .63              3.27+000
                                   2.46       1.00              6.07+000
                                   3.12       1.25              7.53+000
                                   6.31       2.50              9.86+000
                                   8.91       6.00              3.06-001
                                   9.74      10.00              7.55+000
                                  10.92      15.00*             5.19+000
                                  11.42      20.00*             3.06+000
```

TABLE 4. PADRE PRINTOUT OF RESULTS FOR A COMPLETE TEST

```
TEST SITE          KAIS        KAIS        KAIS        KAIS        KAIS        KAIS
TEST DATE         31080       31080       31080       31080       31080       31080
RUN NUMBER            1           2           5           6           7           8
RUN DATE          31080       31080       31180       31180       31280       31280
START TIME         1300        1309        1226        1226        1014        1014
TOTAL MASS    1.710E+01   1.326E+01   1.184E+01   1.858E+01   9.551E+00   1.465E+01

   STD. DIAM.      CUM. % MASS   <D50
       .63            13.73        8.90       12.71        9.38         .58       11.66
      1.00            21.28       13.87       20.78       18.97        5.83       16.51
      1.25            26.68       24.86       26.35       26.40       10.22       22.14
      2.50            45.72       52.63       53.28       47.25       26.34       43.35
      6.00            62.85       79.95       75.21       73.95       43.36       64.98
     10.00            74.00       82.00       82.24       86.18       49.17       77.66
     15.00            87.40       84.62       92.19       93.55       56.51       86.46
     20.00            93.67       87.81       96.48       96.93       65.48       91.48

Data Comparison for 6 outlet runs by RCM

STD. DIAM. NO.   DM/DLOGD     CUMULATIVE             CUM % MASS <D50
(MICRONS) RUNS   (MG/DNCM)    MASS   <D50    AVG.     STD. DEV.    MIN.       MAX.
    .63     5    2.72E+00     1.42E+00       9.49        4.75       .58      13.73
   1.00     6    9.28E+00     2.41E+00      16.21        5.79      5.83      21.28
   1.25     6    9.82E+00     3.35E+00      22.77        6.38     10.22      26.68
   2.50     6    9.79E+00     6.46E+00      44.76        9.83     26.34      53.28
   6.00     6    4.71E+00     9.61E+00      66.72       13.14     43.36      79.95
  10.00     6    7.14E+00     1.09E+01      75.21       13.43     49.17      86.18
  15.00     6    6.24E+00     1.21E+01      83.45       13.64     56.51      93.55
  20.00     6    5.04E+00     1.28E+01      88.64       11.84     65.48      96.93
```

TABLE 5. IRON AND STEEL PARTICLE SIZE DATA SOURCE SUMMARY

		Total No. of Source Tests		Tested under IP Program
Sinter Windbox		12		
Sinter Discharge		3		2
Blast Furnace Cast House		2		2
Basic Oxygen Furnace (BOF)		11		5
Charge	4		2	
Tap	5		2	
Blow	2		1	
Quelle Basic Oxygen Process (QBOP)		3		1
Charge	2			
Blow	1		1	
Open Hearth		4		
EAF		3		
Hot Metal Desulfurization		2		2
Total		40		12

TABLE 6. COKE MANUFACTURING PARTICLE SIZE DATA SOURCE SUMMARY

	Total No. of Source Tests	Tested under IP Program
Charging	1	
Coal Reheating	2	
Pushing	10	1
Quenching	4	4
Combustion Stacks	3	
Total	20	5

TABLE 7. TOTAL PARTICULATE EMISSION FACTORS FOR IRON AND STEEL SOURCE CATEGORY(7)[a]

Source	Units	Particulate Emission Factors		Emission Factor Rating
Sintering				
Windbox emissions	kg/Mg (lb/T) finished sinter			
Uncontrolled				
Leaving grate		5.56	(11.1)	B
After coarse particulate removal		4.35	(8.7)	A
Controlled by dry ESP		0.8	(1.6)	B
Controlled by wet ESP		0.085	(0.17)	B
Controlled by scrubber		0.235	(0.47)	B
Controlled by cyclone		0.95	(1.9)	B
Sinter discharge (breaker and hot screens)	kg/Mg (lb/T) finished sinter			
Uncontrolled		15.6	(31.2)	A
Controlled by baghouse		0.005	(0.01)	A
Controlled by orifice scrubber		0.295	(0.59)	A
Windbox and discharge	kg/Mg (lb/T) finished sinter			
Controlled by baghouse		0.15	(0.3)	A
Blast Furnaces				
Slips	kg (lb)/slip	39.5	(87.0)	D
Uncontrolled casthouse emissions	kg/Mg (lb/T) hot metal			
Furnaces without local evacuation[b]		0.3	(0.6)	B
Furnaces with local evacuation[c]		0.65	(1.3)	B
Taphole and trough only (not runners)		0.15	(0.3)	

(continued)

TABLE 7. (continued)

Source	Units	Particulate Emission Factors		Emission Factor Rating
Hot Metal Desulfurization Emissions ($CaC_2/CaCO_3$ reagents)				
Uncontrolled	kg/Mg (lb/T) hot metal desulfurized	0.54	(1.08)	B
Controlled by baghouse		0.0014	(0.0028)	B
Basic Oxygen Furnaces				
Top blown furnace melting and refining	kg/Mg (lb/T) steel			
Uncontrolled		14.25	(28.5)	B
Controlled by open hood vented to:				
ESP		0.065	(0.13)	A
Scrubber		0.045	(0.09)	B
Controlled by closed hood vented to:				
Scrubber		0.0034	(0.0068)	A
QBOP melting and refining	kg/Mg (lb/T) steel			
Controlled by scrubber		0.028	(0.056)	A
Charging	kg/Mg (lb/T) hot metal			
At source[d]		0.3	(0.6)	A
At building monitor		0.071	(0.142)	B
Tapping	kg/Mg (lb/T) steel			
At source		0.46	(0.92)	A
At building monitor		0.145	(0.29)	B
Hot metal transfer	kg/Mg (lb/T) hot metal			
At source		0.095	(0.19)	A
At building monitor		0.028	(0.056)	B

(continued)

TABLE 7. (continued)

Source	Units	Particulate Emission Factors		Emission Factor Rating
Basic Oxygen Furnaces (continued)				
BOF monitor (all sources)	kg/Mg (lb/T) steel	0.25	(0.50)	B
Electric Arc Furnaces				
Melting and refining	kg/Mg (lb/T) steel			
Uncontrolled				
Carbon steel		19.0	(38.0)	C
Charging, tapping and slagging	kg/Mg (lb/T) steel			
Uncontrolled emissions escaping monitor		0.7	(1.4)	C
Melting, refining, charging, tapping and slagging	kg/Mg (lb/T) steel			
Uncontrolled				
Alloy steel		5.65	(11.3)	A
Carbon steel		25.0	(50.0)	C
Controlled by:[e]				
Building evacuation to baghouse for alloy steel		0.15	(0.3)	A
Direct shell evacuation (plus charging hood vented to common baghouse for carbon steel)		0.0215	(0.043)	C
Open Hearth Furnaces				
Melting and refining	kg/Mg (lb/T) steel	10.55	(21.1)	A
Uncontrolled		0.14	(0.28)	A
Controlled by ESP		0.084	(0.168)	C

(continued)

TABLE 7. (continued)

Source	Units	Particulate Emission Factors		Emission Factor Rating
Teeming				
Leaded steel	kg/Mg (lb/T) steel			
Uncontrolled (as measured at the source)		0.405	(0.81)	A
Controlled by side-draft hood vented to baghouse		0.0019	(0.0038)	A
Unleaded steel				
Uncontrolled (as measured at the source)		0.035	(0.07)	A
Controlled by side-draft hood vented to baghouse		0.008	(0.0016)	A
Machine Scarfing				
Uncontrolled	kg/Mg (lb/T) metal through scarfer	0.05	(0.1)	B
Controlled by ESP		0.0115	(0.023)	
Miscellaneous Combustion Sources[f]				
Boilers, soaking pits and slab reheat furnaces	kg/10^9 J (lb/10^6 Btu)			
Blast furnace gas[g]		0.015	(0.035)	D
Coke oven gas[g]		0.0052	(0.012)	D

(continued)

TABLE 7. (continued)

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[a] All data are from Reference 7 except sinter discharge (uncontrolled and controlled by baghouse) and hot metal desulfurization which were calculated by the author from the original field test data.

[b] Typical of older furnaces with no controls, or for canopy hoods or total casthouse evacuation.

[c] Typical of the large, new technology furnaces with local hoods and covered, evacuated runners. Emissions are higher than without capture systems because emissions are concentrated or not diluted by the outside environment.

[d] Emission factor determined from test at a single QBOP facility. Emissions from a conventional BOF are expected to be less due to the lack of nitrogen blowing.

[e] Building evacuation collects all process emissions, while direct shell evacuation collects only melting and refining emissions.

[f] For fuels such as coal, fuel oil, and natural gas, use the emission factors presented in AP-42, Chapter 1. The rating for these fuels in boilers is A, and in soaking pits and slab reheat furnaces is D.

[g] Emission factor based on methane content and cleaned particulate loading.

TABLE 8. SIZE SPECIFIC EMISSION FACTORS FOR IRON AND STEEL SOURCE CATEGORY[a]

Source Category	Controls	Rating	Cumulative % mass less than 0.5 um	1.0 um	2.5 um	5.0 um	10 um	15 um	Comments
Sinter Plant Windbox	none	D	4	4	5	9	15		
	cyclones	C		37	52	64	74	80	
	scrubber	C	55	75	89	93	96	98	
	ESP	C	18	25	33	48	59	69	
	baghouse	D	4	7	20	48	80		
Sinter Discharge	none	B	0.17	0.6	1.6	4.3	7.3	8.6	
	baghouse	B	0.12	0.13	3	7.5	18	28	
Blast Furnace Casthouse	none	C		15	23	35	51	61	measured in total casthouse evacuation control system.
	none	B		9	15	20	24	26	measured in evacuated hoods and runner cover system.
BOF Charge	none	E		12	22	35	46	56	emissions captured by doghouse type furnace enclosure.
	baghouse	C	2	9	21	32	55	72	emissions captured by doghouse type furnace enclosure.
Tap	none	E		11	37	43	45	50	emissions captured by doghouse type furnace enclosure.
	baghouse	C	4	5	12	22	34	46	emissions captured by doghouse type furnace enclosure.
Refining	scrubber	B	34	50	57	59	64	70.3	closed hood system.
QBOP Charge	none	E		1	16	34	42		emissions captured by doghouse type furnace enclosure.
Refining Cycle	scrubber	D	45	52	56	58	68	85	closed hood system.
Open Hearth	none	E	1	21	60	79	83		
	ESP	E		21	39	47	53		may not be representative-test outlet size dist. was larger than inlet - may indicate reentrainment problem.
Electric Arc Furnace	none	D	8	23	43	53	58	61	combined cycle emissions captured by canopy and side draft hoods.
	baghouse	E		74	74	74	76	80	information on control system not available.
Hot Metal Desulfurization	none	E			11	17	25	32	torpedo ladle desulfurization with CaC_2 and $CaCO_3$.
	baghouse	D	7	16	45	63	75	83	torpedo ladle desulfurization with CaC_2 and $CaCO_3$.

[a] All data are from Reference 7 except sinter discharge, BOF refining, and hot metal desulfurization which were calculated by the author from the original field test data.

TABLE 9. SOURCE EMISSION FACTORS FOR COKE MANUFACTURING[8] SOURCE CATEGORY

Type of Operation	Particulate Emission Factor Rating	Particulates[a]	
		kg/Mg	lb/ton
Coal crushing with cyclone	D	0.55	0.11
Coal preheating			
Uncontrolled	C	1.75	3.50
With scrubber	C	0.125	0.26
With wet ESP	C	0.006	0.012
Coal charging			
Uncontrolled	E	0.24	0.48
With sequential charging	D	0.008	0.016
With scrubber on larry car	E	0.017	0.034
Door leaks (uncontrolled)	D	0.27	0.54
Coke pushing			
Uncontrolled	A	0.58	1.15
With ESP[b]	C	0.225	0.45
With venturi scrubber[c]	E	0.08	0.17
With baghouse[d]	E	0.034	0.068
Mobile scrubber car[e]	E	0.034	0.069
Quenching			
Uncontrolled (dirty water)[f]	D	2.62	5.24
Uncontrolled (clean water)[g]	D	0.57	1.13
With baffles (dirty water)[f]	A	0.65	1.30
With baffles (clean water)[g]	A	0.27	0.54
Combustion stacks			
Uncontrolled (COG)	A	0.234	0.47
Uncontrolled (BFG)	A	0.085	0.17
With ESP	E	0.046	0.091
With baghouse	C	0.075	0.15
Coke handling with rotoclone[h]	C	0.003	0.006

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[a] Emission factors expressed as units per weight of coal charged.

[b] Emission collected by coke side shed.

[c] Emissions collected by travelling hood or Minister Stein system.

[d] Emissions collected by baghouse (fabric filters).

[e] Emission factor does not take into consideration capture efficiencies of the enclosed hot coke car at the point of emissions origin.

[f] Dirty water >5000 mg/l total dissolved solids.

[g] Clean water <1500 mg/l total dissolved solids.

[h] Handling defined as crushing and screening.

TABLE 10. SIZE SPECIFIC EMISSION FACTORS FOR COKE MANUFACTURING SOURCE CATEGORY(8)

Process	Emission Factor Rating	Particle Size um	Cumulative Mass % <Stated Size	Cumulative[a] Mass Emission Factors kg/Mg	lb/ton
Coal Preheating Uncontrolled	C	0.5	44	0.8	1.5
		1.0	48.5	0.8	1.7
		2.0	55	1.0	1.9
		2.5	59.5	1.0	2.1
		5.0	79.5	1.4	2.8
Controlled with Venturi Scrubber	C	0.5	78	0.10	0.20
		1.0	80	0.10	0.20
		2.0	83	0.10	0.21
		2.5	84	0.11	0.21
		5.0	88	0.11	0.22
		10.0	94	0.12	0.24
Coal Charging Sequential	D	0.5	13.5	0.001	0.002
		1.0	25.2	0.002	0.004
		2.0	33.6	0.003	0.005
		2.5	39.1	0.003	0.006
		5.0	45.8	0.004	0.007
		10.0	48.9	0.004	0.008
Coke Pushing Uncontrolled	A	0.5	3.1	0.02	0.04
		1.0	7.7	0.04	0.09
		2.0	14.8	0.09	0.17
		2.5	16.7	0.10	0.19
		5.0	26.6	0.15	0.30
		10.0	43.3	0.25	0.50
Controlled with Venturi Scrubber[b]	E	0.5	24	0.02	0.04
		1.0	47	0.04	0.08
		2.0	66.5	0.05	0.11
		2.5	73.5	0.06	0.12
		5.0	75	0.06	0.13
		10.0	87	0.07	0.15
Mobile Scrubber Car Travel Mode	C	1.0	2.0	0.0007	0.001
		2.0	3.2	0.001	0.002
		2.5	3.5	0.001	0.003
		5.0	6.5	0.002	0.005
		10.0	10.0	0.004	0.007

(continued)

TABLE 10. (Continued)

Process	Emission Factor Rating	Particle Size um	Cumulative Mass % <Stated Size	Cumulative Mass Emission Factors kg/Mg	Cumulative Mass Emission Factors lb/ton
Coke Pushing (continued)					
Mobile Scrubber Car[c] Push Mode	C	1.0	27.9	0.010	0.021
		2.0	29.5	0.011	0.022
		2.5	30.0	0.011	0.022
		5.0	30.0	0.011	0.022
		10.0	32.0	0.012	0.024
Quenching Uncontrolled (dirty water)[d]	D	1.0	13.8	0.36	0.72
		2.5	19.3	0.51	1.01
		5.0	21.4	0.56	1.12
		10.0	22.8	0.60	1.19
		15.0	26.4	0.69	1.38
Uncontrolled (clean water)[e]	D	1.0	4.0	0.02	0.05
		2.5	11.1	0.06	0.13
		5.0	19.1	0.11	0.22
		10.0	30.1	0.17	0.34
		15.0	37.4	0.21	0.42
With Baffles (dirty water)[d]	A	1.0	8.5	0.06	0.11
		2.5	20.4	0.13	0.27
		5.0	24.8	0.16	0.32
		10.0	32.3	0.21	0.42
		15.0	49.8	0.32	0.65
With Baffles (clean water)[e]	A	1.0	1.2	0.003	0.006
		2.5	6.0	0.02	0.03
		5.0	7.0	0.02	0.04
		10.0	9.8	0.03	0.05
		15.0	15.1	0.04	0.08
Combustion Stacks	A	1.0	77.4	0.18	0.36
		2.0	85.7	0.20	0.40
		2.5	93.5	0.22	0.44
		5.0	95.8	0.22	0.45
		10.0	95.9	0.22	0.45

[a] Emission factors expressed as units per weight of coal charged.

[b] Emissions collected by travelling hood or Minister Stein system.

[c] Does not consider capture efficiency of the enclosed hot car at the point of emissions origin.

[d] Dirty water: >5000 mg/l total dissolved solids

[e] Clean water: <1500 mg/l total dissolved solids

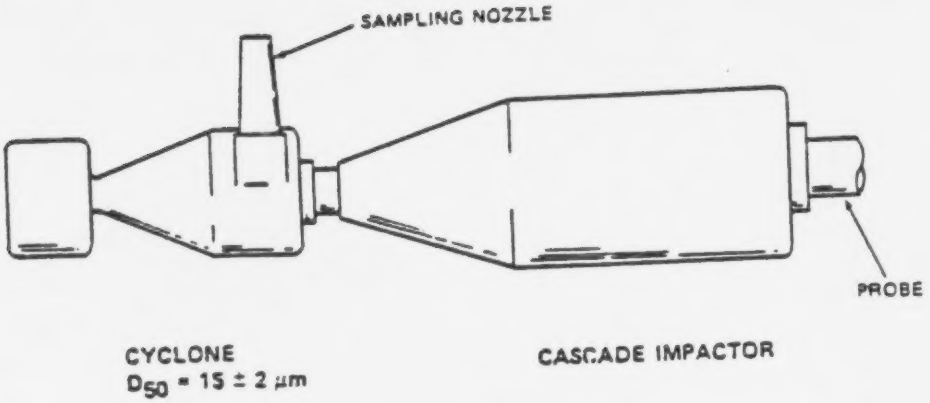

SAMPLING NOZZLE
PROBE
CYCLONE
D_{50} = 15 ± 2 µm
CASCADE IMPACTOR

Figure 1. Cascade impactor/precollector cyclone system.

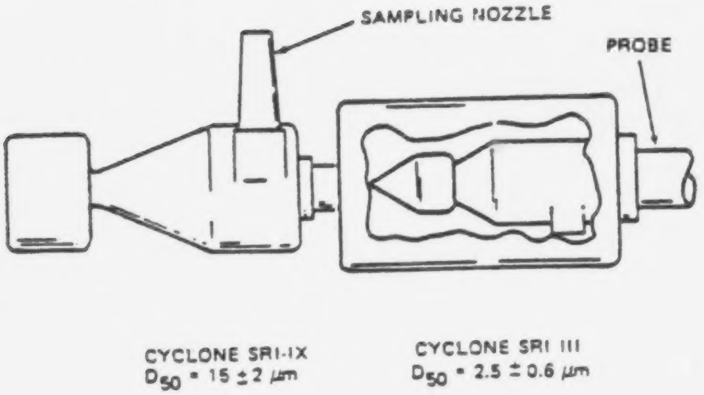

SAMPLING NOZZLE
PROBE
CYCLONE SRI-IX
D_{50} = 15 ± 2 µm
CYCLONE SRI III
D_{50} = 2.5 ± 0.6 µm

Figure 2. Dual-cyclone sampler for inhalable particles.

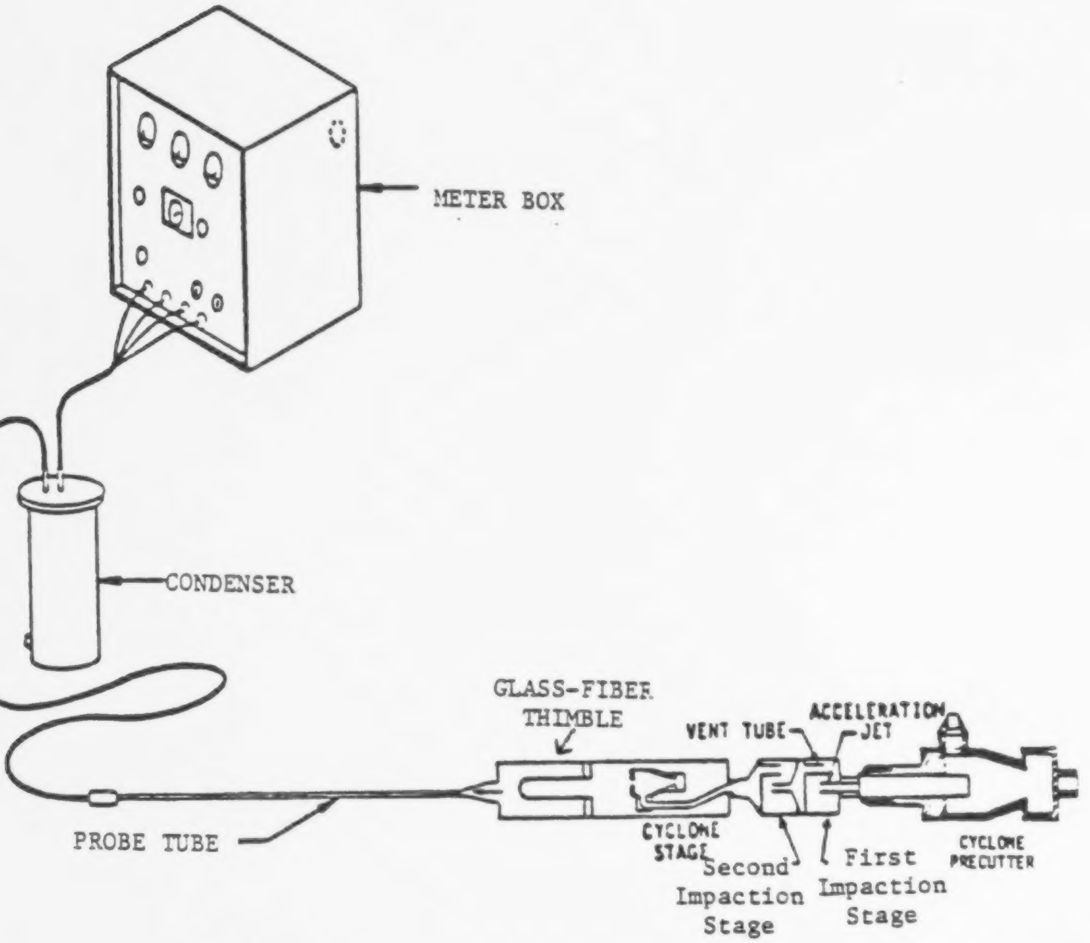
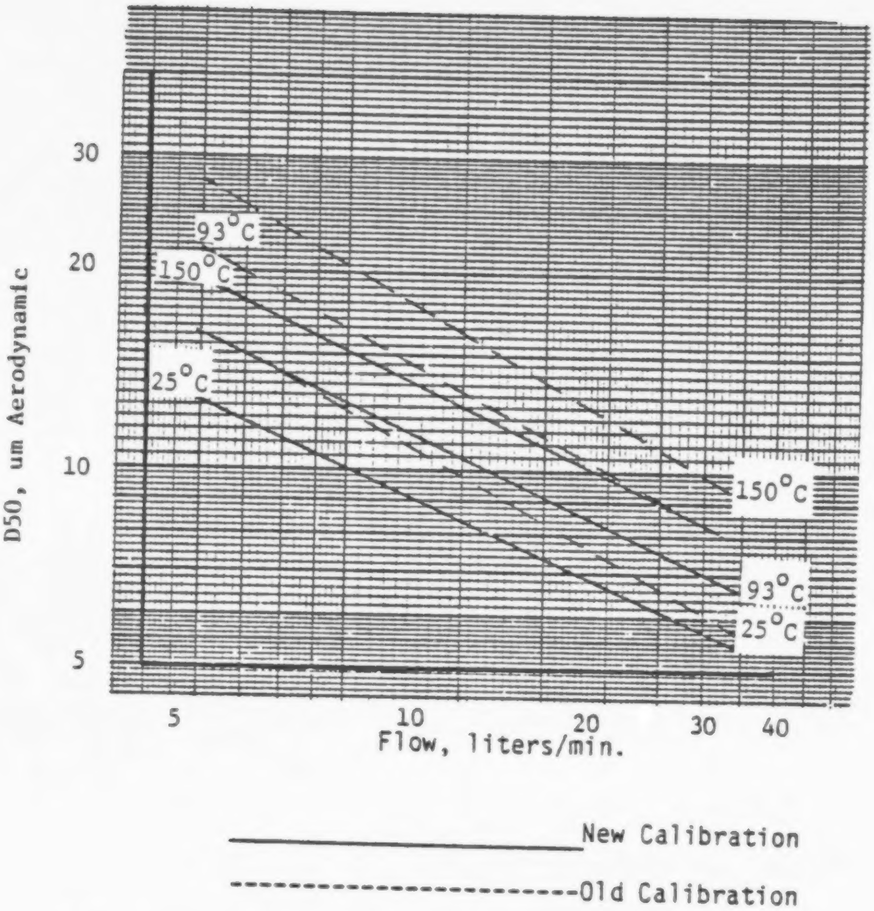

METER BOX
CONDENSER
GLASS-FIBER THIMBLE
VENT TUBE
ACCELERATION JET
PROBE TUBE
CYCLONE STAGE
Second Impaction Stage
First Impaction Stage
CYCLONE PRECUTTER

Figure 3. Andersen heavy grain loading impactor sampling train shown with cyclone precutter.



Correct Equation: $D_{50} = (0.0632u-5.46)- Q^{0.47}$
Where: u = viscosity up
Q = flow in actual cfm

FIGURE 4. Comparison of old and new cyclone IX calibration.

ENDNOTES

References

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ON THE RELATIONSHIP BETWEEN AMBIENT PARTICULATE LEVELS AND STEEL PLANT PRODUCTION LEVELS

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ABSTRACT

Historically, air quality modeling studies of compliance with ambient standards have been based on emissions from steel plants assumed operating at 100% of rated capacity. More recently, agencies have been concerned with air quality impacts when plants are operating at less than 100% of capacity. The reasoning is that, while emission rates may decrease as production decreases, this reduction may be offset by increases in ground level concentrations due to reductions in plume buoyancy assumed to be associated with lower plant operating levels. This paper explains the approach taken to answer the question of how ambient TSP levels are related to plant operating levels in the case of the three major steel plants in Lake County, Indiana.

All steel plant sources were examined individually to determine how emission parameters (buoyancy flux and emission rate) change as a function of plant production levels. Ground level concentrations of conventional stack sources, e.g., large boilers, typically do increase as their fuel firing rate decreases. For most sources, however, the reverse holds. Sources controlled by scrubbers and baghouses retain the same buoyancy flux almost independent of operational levels while particulate emissions may actually decrease. In the steel-making shops, the number of furnace heats, but not the size of each heat, is reduced as production falls, and so roof monitor emissions buoyancy flux holds constant. Many other sources, when operating, run at or near maximum levels. For example, soaking pits typically operate in a bimodal state, either at close to rated capacity or shutdown, which tends to eliminate the influence on plume buoyancy flux of changes in plant production levels. Finally, process fugitive emission rates vary directly with plant production levels and so, as production decreases, fugitive emissions decrease proportionally.

This study demonstrated that ambient particulate levels from integrated steel plants decrease as plant production levels decrease, rather than as previously thought.

Since the information in this document has not been funded, wholly or in part, by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's peer and administrative review. Therefore, it does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

INTRODUCTION

The industrialized northern portion of Lake County, Indiana was designated a non-attainment area for total suspended particulate (TSP) in 1979. To assist regulatory agencies in developing an attainment plan and revision to the state implementation plan (SIP) in response to this designation, major industries there voluntarily formed an ad hoc organization, the Lake County Industry Task Force. The Task Force sponsored technical studies and provided plant-specific input that formed the basis for subsequent state regulatory revisions and a SIP revision, currently under EPA review.

EPA's review of the SIP revision coincided with recent years of reduced production in the steel industry, which triggered a new EPA concern. The revised state regulations express limits on many sources in terms of "pounds per hour", independent of source operating level. These limits were based on compliance demonstration modeling of all sources at rated capacity, i.e., maximum emission rates with stack velocities and temperatures set at rated maximum, all in accordance with agency requirements.

EPA then decided to require a "reduced load modeling analysis" because of concerns that, at reduced operating levels, ambient TSP concentrations may increase relative to the concentrations predicted at rated capacity. EPA concerns were predicated on the following reasoning: for sources with an emission limit in "lb/hr," stack velocity and/or temperature will drop as the operating level drops, but if the stack is still allowed to emit at the same maximum rate, the ground level concentration will increase as operating level decreases because stack emission buoyancy flux (and thus plume rise) decreases while the emission rate remains constant. In other words, maximum allowable emissions released from a stack at lower than modeled velocity/temperature associated with lower operating level would increase ground level impact.

APPROACH

EPA suggested a reduced load analysis should be done for fuel burning and uncontrolled non-batch process sources with individual allowable limits greater than 5.7 lb/hr (i.e., 25 tons/yr) or a total plant allowable limit greater than 22.8 lb/hr (i.e., 100 tons/yr). All units in a plant with total plant emissions above 22.8 lbs/hr (regardless of individual unit emissions) and all units above 5.7 lb/hr (regardless of total plant emissions) had to be included in the analysis.

A source did not have to be modeled at reduced load if the above criteria were not met, or if:

- A company could document with actual operating records that stack exit temperature and velocity do not change as actual operating level changes; or

- Individual units operated consistently at or near maximum operating levels; or
- A source had a supplemental regulatory limit in lb/million BTU, lb/ton, or gr/dscf (i.e., a rate-dependent emission limit).

In order to respond to EPA's request, all TSP sources with a fixed numerical limit in pounds per hour were identified. The companies whose sources were identified were then contacted and the EPA requirements for reduced load modeling were explained. Companies' responses to EPA's requirements were compiled and, essentially, all sources in all three major steel plants fell within the criteria. Those plants include LTV Steel's Indiana Harbor Works, Inland Steel's Indiana Harbor Works, and U.S. Steel's Gary Works.

The reduced load modeling analysis was conducted consistent with the protocol that had been established for this specific attainment plan as follows:

- The CDMQC model;
- The complete Lake County TSP receptor network of 158 receptors;
- The 1973 dispersion climatology from Midway Airport and Peoria;
- The "Larsen Transform" to convert the annual arithmetic mean to an annual geometric mean and second-high 24-hour concentration; and
- The emissions for the affected sources plus the inventory of all other emissions as used in the compliance demonstration.

Operating levels for the "reduced load modeling" were set at 85 and 70 percent of capacity. These levels were chosen for the following reasons. One, having results for 100, 85 and 70 percent of capacity would provide three equally spaced data points that could be used for extrapolation to other operating levels. Two, results from these three operating levels would show whether impacts at receptors rise or fall with operating level, thus indicating whether further modeling at even lower levels would be necessary. Three, based on conversations with the companies, 85 and 70 percent of capacity are realistic reduced operating levels, except during economically depressed conditions.

RESULTS

The entire inventory of both Inland Steel and U.S. Steel sources fall within the EPA criteria for analysis. All Inland Steel and U.S. Steel facilities, when operating, generally are at some production level below the absolute maxima modeled in the compliance demonstration. In the cases of both fuel-fired sources and process sources, the preferred operating mode is to run individual units, if at all, as close to capacity as possible in order to minimize fuel and labor costs while just meeting specific production requirements. Thus, when peak production is not needed, production schedules usually are curtailed by taking soaking pits and reheat furnaces off line and reducing the frequency of process batch operations. In the case of combination fuel burning-process sources, reducing production may reduce stack exit velocities and temperatures but process fugitive emissions also are reduced. Because these plants are operated this way, all sources in the plant had to be treated consistently in order to do a realistic reduced load modeling analysis.

For example, if iron production in blast furnaces is reduced below rated capacity, the volume of blast furnace gas burned by the stoves, which provide hot blast air to the furnace, also is reduced to slow down the iron melting rate. Thus, process fugitive source emission rates (associated with iron production) and stack exit velocities from furnace gas combustion vary on a proportional basis. The net result is greater impact of emissions from stove stacks, but lower impact from the fugitive emissions.

Similarly, if coke battery production is reduced below rated capacity, the volume of coke oven gas fired also is reduced. Normally, coke production is reduced by heating the coal in the ovens at a lower temperature for a longer period of time. Thus, process fugitive source emission rates (associated with coke production) and underfire stack exit velocities vary on a proportional basis. The net result is greater impact of emissions from the coke oven stacks, but lower impact from the fugitive emissions associated with coke pushing.

As these examples show, fuel combustion throughout the plant diminishes in concert with production of coke, iron and steel. As a result of this integrated operation, stack exit velocities and process fugitive emission rates are inextricably linked and this linkage must be reflected in any reduced load modeling analysis.

Accordingly, the reduced load modeling was set up as follows for Inland Steel and U.S. Steel sources:

- For the 85 percent of capacity model run, exit velocities of all fuel-fired sources were reduced to 85 percent of maximum while emission rates remained at regulatory limits, and all process source emission rates were reduced to 85 percent of maximum.
- For the 70 percent of capacity model run, exit velocities of all fuel-fired sources were reduced to 70 percent of maximum while emission rates remained at regulatory limits, and all process source emission rates were reduced to 70 percent of maximum.

Exit velocities and temperatures of the process fugitive sources were held at their rated capacity values for the following reasons:

- Coke Batteries - exit velocities were set to zero and temperatures were set to ambient in all modelling. (As required by EPA for this compliance demonstration, coke battery fugitive emissions could not be modeled with buoyancy or momentum).

- Basic Oxygen Furnace and Electric Arc Furnace Shop Roof Monitors production rates in these shops normally are reduced not by cutting the size of individual furnace heats (charges) but rather by cutting the number of heats per day; thus, roof monitor exhaust velocities and temperatures, when shops are operating, do not vary with production level.

- Blast Furnace Cast House Roof Monitors - the same reasoning applies here as for the above roof monitors.

- Other Sources - control devices such as baghouses, scrubbers or precipitators are equipped with fans operated at constant speed to maintain approximately constant exit velocities over a wide range of reduced production rates; and temperatures do not vary appreciably.

Sources at LTV Steel for the reduced load modeling analysis were treated as follows:

- Utility Boilers #1 & 2: not modeled because they run at capacity or not at all.

- Utility Boilers #3-8: modeled with velocities reduced to 85 and 70 percent of maxima.

- #2 Sheet Mill, CRSM Boilers 5-8: not modeled because they have a supplemental regulatory limit in lb/mmBTU

- Hot Strip Mill, Slab Heat Furnaces #1-3: not modeled because they have a supplemental regulatory limit in lb/mmBTU

- Seamless Mill Reheat, Rotary and Normalizing Furnaces: modeled with velocities reduced to 85 and 70 percent of maxima.

- #2 Slab Mill Furnaces: not modeled because they have a supplemental regulatory limit in lb/mmBTU.

- Blast Furnace Stoves #1-4: as at Inland Steel and U.S. Steel, when iron production is reduced, the volume of blast furnace gas burned by the stoves decreases; thus both the emission rate and stack velocity are reduced to 85 and 70 percent of maxima for the reduced load modeling analysis.

- Basic Oxygen Furnace Main Stacks: not modeled because temperature and velocity do not change with production rate because emissions go through an electrostatic precipitator.

For all the remaining non-steel plant sources that were included under the analysis criteria, stack exit velocities are reduced to 85 and 70 percent of maxima while emissions remain at regulatory limits because they are fuel burning sources.

At this point, it should be noted that emissions from non-traditional fugitive dust sources such as roads and material handling were not varied in the analysis, even though such emissions likely would drop with the reduction in plant production level. A more detailed and sophisticated analysis of operating at reduced levels should include the effect on emissions and ambient air quality from changes in these activities.

Reduced load modeling results for selected Lake County receptors are shown in Table 1 (the receptor network is shown on Figure 1). The results show that compliance is still maintained at reduced operating levels. In fact, predicted concentrations are lowest at the lowest operating rate (70 percent) and highest at the highest operating rate (rated capacity).

CONCLUSIONS

Generally, when modeling at reduced capacity, a degradation in air quality might be expected. But, when the modeling of the complex, integrated plants in Lake County is done realistically, the reduced impact of process fugitive emissions related to reduced plant operating levels actually improves air quality in the region. If reductions in nontraditional fugitive emissions also were included, the effect likely would be even more pronounced. Thus, the most stringent test of compliance in Lake County remains the rated capacity case.

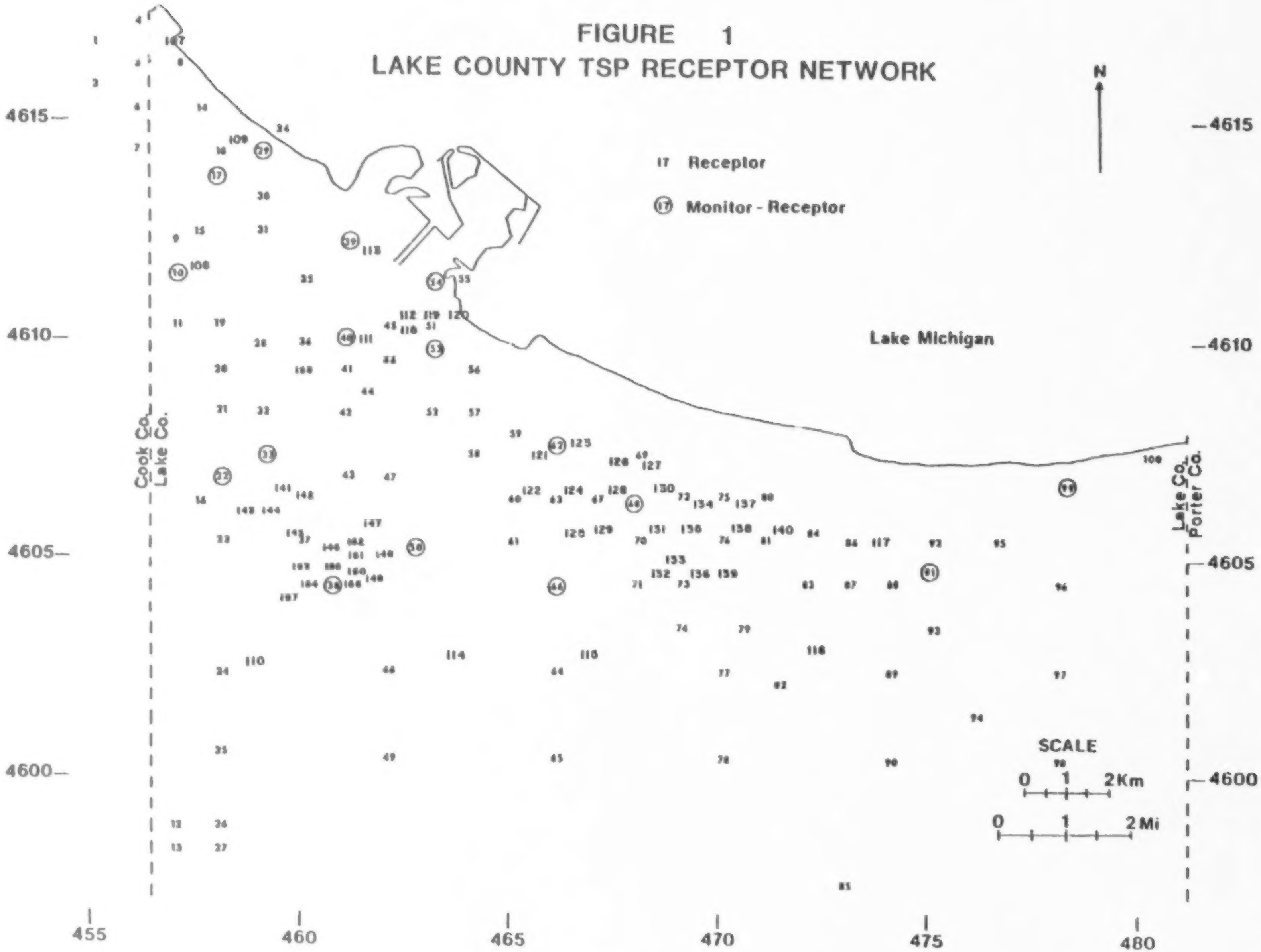
TABLE 1

REDUCED LOAD MODELING RESULTS FOR SELECTED RECEPTORS

	Annual Geometric Mean TSP Concentrations (ug/m^3)				
Receptor	100% of Capacity	85% of Capacity	Net Change at 85%	70% of Capacity	Net Change at 70%
8	73	73	0	72	-1
14	74	74	0	73	-1
39	68	67	-1	66	-2
47	74	73	-1	73	-1
55	66	64	-2	62	-4
112	67	66	-1	64	-3
113	69	68	-1	67	-2
155	74	74	0	74	0

	Second High 24-Hour TSP Concentrations (ug/m^3)				
Receptor	100% of Capacity	85% of Capacity	Net Change at 85%	70% of Capacity	Net Change at 70%
8	213	212	-1	211	-2
14	217	215	-3	214	-3
39	255	251	-3	247	-8
47	228	225	-3	223	-5
55	256	248	-8	241	-15
112	259	254	-5	248	-11
113	260	255	-5	250	-10
155	258	256	-2	255	-3

FIGURE 1
LAKE COUNTY TSP RECEPTOR NETWORK


N
17 Receptor
⑰ Monitor - Receptor
Lake Michigan
Cook Co.
Lake Co.
Lake Co.
Porter Co.
SCALE
0 1 2Km
0 1 2 Mi
4615
4610
4605
4600
455
460
465
470
475
480

REVIEW OF PM-10 MONITORING REGULATIONS

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ABSTRACT

The March 20, 1984 proposed revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter and related monitoring requirements are reviewed. The existing NAAQS for total suspended particulate and the proposed new standards for particulate matter with an aerodynamic diameter smaller than or equal to a nominal 10 micrometers (PM-10) are discussed briefly. The remaining discussion focuses on the new Federal Reference Method (FRM) for the measurement of PM-10 in the ambient air and the requirements concerning ambient air monitoring reference and equivalent methods.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative policies and approved for presentation and publication.

INTRODUCTION

As a result of its re-evaluation of the health and welfare criteria for particulate matter, EPA proposed, on March 20, 1984, the following revisions to the National Ambient Air Quality Standards (NAAQS) for particulate matter(1):

1. That the measurement of Total Suspended Particulate Matter (TSP) as an indicator for ambient concentrations of particulate matter be replaced for both of the primary standards by a new indicator that measures the concentration of only those particles with an aerodynamic diameter smaller than or equal to a nominal 10 micrometers (PM-10);

2. That the level of the 24-hour primary standard be changed to a value to be selected from a range of 150 to 250 $\mu g/m^3$ and that the current deterministic form of the standard be replaced with a statistical form that permits no more than one expected exceedance of the standard level per year;

3. That the level of the annual primary standard be changed to a value to be selected from a range of 50 to 65 $\mu g/m^3$ and the form be expressed as an expected annual arithmetic mean; and

4. That the current 24-hour secondary TSP standard be replaced by an annual TSP secondary standard to be selected from a range of 70 to 90 $\mu g/m^3$, expected annual arithmetic mean.

The existing primary and secondary standards for TSP and these proposed new standards for PM-10 are shown in Table I.

In addition to the revisions to the NAAQS, EPA also proposed a new Federal Reference Method (FRM) for the measurement of PM-10 in the ambient air (proposed new Appendix J of 40 CFR Part 50) and appropriate revisions to the regulations concerning Ambient Air Monitoring Reference and Equivalent Methods (40 CFR Part 53) and Ambient Air Quality Surveillance (40 CFR Part 58)(1). This presentation will focus primarily on the new FRM and on the revisions to the reference and equivalent method regulations.

NEW PM-10 REFERENCE METHOD

The current appendices to 40 CFR Part 50 describe requirements for reference methods to be used for measuring each of the pollutants for which an NAAQS has been established. For each pollutant, a corresponding appendix specifies either a complete, unique, manual reference method (e.g., TSP, SO_2, Pb) or a measurement principle and calibration procedure applicable to automated reference methods, which must also meet performance requirements specified in 40 CFR Part 53 (e.g., CO, O_3, NO_2).

A new Appendix J, proposed to be added to Part 50, describes the reference method for PM-10. Appendix J deviates somewhat from the scheme established for TSP (Appendix B) in that the method described is considered a manual method even though the requirements resemble the measurement principle and performance requirements normally prescribed for automated methods. This approach was taken to provide for greater flexibility to allow for the use of various currently available particulate matter samplers and to encourage continuing improvements and innovative new sampler designs.

The proposed reference method for PM-10 is based on discrimination and selection of PM-10 particles by inertial separation in a specially shaped inlet, followed by conventional filtration of a measured volume of sampled air and determination of the net weight gain of the filter. The sampler (or sampler inlet) would be required to meet performance specifications and would have to be tested according to the explicit test procedures prescribed in 40 CFR Part 53, which are discussed in detail in the following section. Methods for PM-10 that meet all requirements would be designated as PM-10 reference methods and would be identified, in most cases, by the manufacturer and model of the sampler. Wherever feasible, the requirements in Appendix J are prescribed as functional or performance specifications rather than design specifications to allow maximum flexibility in designing or configuring PM-10 samplers. Sampler shape, inlet geometry, filter material and size, operational flow rate, degree of automation, and so forth are all specified in terms of required function or performance.

Accordingly, the proposed reference method prescribes no specific flow rate for PM-10 samplers. High flow rate samplers, such as the existing high-volume samplers equipped with a size-selective inlet, would be approved if they meet all of the performance requirements. Medium and low flow samplers would also be allowed, provided enough mass is collected to meet a reproducibility specification. PM-10 samplers would have to be designed to minimize measurement errors resulting from filter handling operations such as conditioning, weighing, and installation on and removal from samplers.

An alkalinity specification is included that would disallow the use of excessively alkaline filter media, which could lead to possible measurement errors from artifact formation. Filters meeting this specification should show little or no sulfate artifact but may be subject to errors due to nitrate artifact. However, for most sampling locations, PM-10 mass concentration errors due to positive nitrate artifact or loss of nitrate by volatilization or chemical rection are expected to be small. The proposed filter specifications are intended to be minimum requirements when measurement of PM-10 mass concentration is of primary concern. Users would need to consider additional filter requirements if other sampling objectives were to be met.

PM-10 samplers would be required to have the capability of collecting valid samples at ambient concentration levels consistent with the proposed NAAQS. A filter's capability of withstanding high particle mass loadings under a variety of environmental conditions without overloading (clogging) is an important concern. Ideally, the pressure drop across the filter should be sufficiently low to minimize the potential for overloading. To further minimize this possibility, samplers should have the capability of maintaining normal flow rates over as wide a range of pressure drop as is practical. Sampler manufacturers have been encouraged to consider the potential for filter overloading in designing their samplers and in selecting their recommended filter media. Samplers that incorporate automatic filter-changing mechanisms to switch from a particle-loaded filter to a fresh filter during the 24-hour sample period would be allowed, provided the reproducibility of the PM-10 measurement met the required specification.

Sampler manufacturers would be required to provide sampler purchasers with an operation or instruction manual containing detailed procedures for calibration and operation of the sampler, as well as recommendations regarding appropriate filter media and type of analytical balance required for mass determinations. Such a manual would be required by 40 CFR Part 53, which would require submission of the manual as part of the manufacturer's application for a reference method determination.

PERFORMANCE REQUIREMENTS FOR PM-10 SAMPLERS

Similar to the current manual reference methods for TSP and lead, the proposed PM-10 reference method would require a sampler for collecting particulate samples for subsequent analysis. However, while the sampler required in the TSP and lead methods is explicitly specified by design and dimensions and must be reproduced precisely, the sampler required by the new PM-10 reference method is specified primarily by performance, together with explicit test procedures to be used to determine acceptability. This approach allows for the use of currently available and tested sampler designs while providing greater flexibility and opportunity to encourage improvements and innovations in future sampler designs. It is also consistent with the approach used for specifying reference methods for several other criteria pollutants (CO, O_3, and NO_2), and more readily facilitates the designation of equivalent methods. The appropriate performance specifications and test procedures would be added to 40 CFR Part 53, along with the similar existing performance specifications, test procedures, and other requirements currently provided for reference and equivalent methods for most of the other pollutants for which a NAAQS has been established. The principal change proposed to Part 53 is the addition of a new Subpart D, which prescribes performance specifications and test procedures specifically applicable to candidate methods for PM-10. Specifications and associated test procedures have been proposed in Subpart D for sampling effectiveness (for both liquid and solid particles), 50 percent cutpoint, reproducibility, and flow rate stability.

The performance specifications proposed for PM-10 candidate methods are shown in Table II. Sampling effectiveness refers to the portion (percent) of particulate matter collected (collection efficiency) at a specific particle size (aerodynamic diameter). PM-10 samplers normally have a smooth, S-shaped sampling effectiveness curve dropping from near 100% to near 0% as the particle size increases from 1 to 50 micrometers (μm). The 50 percent cutpoint is the particle size (point on the sampling effectiveness curve) at which the sampling effectiveness is 50 percent. The proposed 50 percent cutpoint has been established at 10 ± 1 μm. The acceptability of the sampling effectiveness of a candidate PM-10 sampler would be tested by comparing it to the sampling effectiveness of a specified "ideal" sampler.

A candidate PM-10 sampler would be required to have a 50 percent cutpoint of 10 ± 1 μm, and would have to produce an expected PM-10 mass concentration measurement within ± 10 percent of the expected PM-10 mass concentration calculated for the ideal sampler, assuming a specified typical ambient particle distribution. The ideal sampler has a 50% cutpoint of 10.0 μm aerodynamic particle diameter, with larger particles collected with substantially lower efficiency and smaller particles with greater (up to 100%) efficiency. These requirements were designed to approximate particle penatration to the thoracic region of the human respiratory tract, and were obtained from a regression equation for extrathoracic deposition of particles in the human respiratory tract during mouth breathing(2). When this regression equation is transformed into a thoracic penetration equation, a model for the sampling effectiveness curve for the ideal sampler is obtained.

The expected mass concentration measured by the ideal sampler is calculated by integrating the product of the sampling effectiveness curve for the ideal sampler and a specified typical ambient particle distribution. The mass distribution data of Lundgren and Paulus(3) for a typical urban atmosphere was selected for the ambient particle distribution. The integration of the product of the ideal sampler's effectiveness curve (or function) and the typical ambient particle mass distribution results in a calculated mass concentration measurement for the ideal sampler of 52.3 $\mu g/m^3$.

The tests for particle sampling effectiveness of a candidate PM-10 sampler would be conducted in a wind-tunnel test facility. Replicate measurements of liquid particle sampling effectiveness for the five particle sizes and 3 wind speeds shown in Table III would be required. These test data would then be used to plot the sampling effectiveness curve for the candidate sampler (or sampler inlet) at each of the three wind speeds. As with the ideal sampler, integration of the product of the sampling effectiveness curve for the candidate sampler and the ambient particle distribution yields an expected mass concentration for the candidate method. To pass the liquid particle sampling effectiveness test, the expected mass concentration for the test sampler (for all 3 wind speeds) would have to be within ± 10 percent of that predicted for the ideal sampler. The 50 percent cutpoint of the test sampler is determined from the liquid particle sampling effectiveness curves and would have to be 10 ± 1 μm at each of the three wind speeds.

A test for solid particle sampling effectiveness would also be required to demonstrate that bouncy particles larger than 10 μm are not unintentionally collected by candidate PM-10 samplers. The test would be conducted in a wind-tunnel using 20 μm particles and wind speeds of 8 and 24 km/hr. Performance of a candidate PM-10 sampler would be acceptable if the sampling effectiveness for solid particles is no more than 5 percent (absolute sampling effectiveness) above that obtained for liquid particles of the same size.

The reproducibility and flow rate stability of a candidate method would be tested on three identical PM-10 samplers simultaneously sampling ambient air for 5 sample periods of 24 hours each. For each of the 5 sets of PM-10 concentration measurements, the reproducibility is calculated as the coefficient of variation and would have to be 15 percent or less to be acceptable. To determine flow rate stability, the flow rate of each test sampler would be recorded at the beginning and end of each 24-hour sample period. For performance to be acceptable, the percent difference between the initial and final flow rates would have to be within ± 10 percent of the initial flow rate for each of the test samplers and sample periods.

The proposed amendments to Part 53 also allow designation of equivalent methods for PM-10 based on measurement principles different from the principle described for PM-10 reference methods in Part 50. Candidate equivalent methods for PM-10 would have to meet the performance requirements of Subpart D as described above, as well as new comparability requirements for PM-10 methods proposed to be added to Subpart C, which prescribes procedures for determining comparability between candidate methods and reference methods. The collection of 5 sets of simultaneous 24-hour PM-10 samples with a reference method sampler and with 3 candidate method samplers at each of 3 different test sites would be required for determining comparability of candidate equivalent methods to a reference method. These samples would be analyzed by the reference or candidate method, as appropriate, to obtain the corresponding PM-10 measurements. For each candidate method measurement, the percent difference between the measurement and the corresponding reference method measurement would be calculated and compared to the allowable specification (± 20 percent of the corresponding reference method measurement). No more than one difference per test site would be allowed to exceed the specified limit to pass the comparability test. The three test sites would have to be located in geographical areas having particulate matter of differing character or composition so that the test sampler would be tested under a variety of particulate matter conditions.

REFERENCES

1. U.S. Environmental Protection Agency, National Ambient Air Quality Standards for Particulate Matter, Ambient Air Quality Surveillance for Particulate Matter, and Ambient Air Monitoring Reference and Equivalent Methods. Proposed Rules, Federal Register 49:10408, 1984.

2. Chan, T.C., and M. Lippman. Experimental Measurement and Empirical Modeling of the Regional Deposition of Inhaled Particles in Humans. AIHA Journal 41:390, 1980.

3. Lundgren, D.A., and H.J. Paulus. The Mass Distribution of Large Particles. JAPCA 25:1227, 1975.

TABLE I. AIR QUALITY STANDARDS FOR PARTICULATE MATTER

Existing Standards (TSP)

Primary Standard:	Secondary Standard:
24-hour - 260 $\mu g/m^3$	24-hour - 150 $\mu g/m^3$
Annual - 75 $\mu g/m^3$	Annual - 60 $\mu g/m^3$

Proposed New Primary Standard (PM-10)

24 hour - a value to be selected from the range, 150 to 250 $\mu g/m^3$

Annual - a value to be selected from the range, 50 to 65 $\mu g/m^3$

Proposed New Secondary Standard (TSP)

Annual - a value to be selected from the range, 70 to 90 $\mu g/m^3$

TABLE II. PERFORMANCE SPECIFICATIONS FOR PM_{10} SAMPLERS

Performance parameter	Units	Specification
1. Sampling effectiveness	%	
A. Liquid particles		Expected mass concentrations calculated from the sampling effectiveness curves for all 3 wind speeds must be within ±10% of that calculated for the ideal sampler.
B. Solid particles		Sampling effectiveness must be no more than 5% above that obtained for liquid particles of same size.
2. 50 Percent cutpoint	μm	10±1 μm aerodynamic diameter.
3. Reproducibility	%	15% coefficient of variation for three collocated samplers.
4. Flow rate stability	%	Within ±10% of initial flow rate over 24-hours.

TABLE III. PARTICLE SIZES AND WIND SPEEDS FOR SAMPLING EFFECTIVENESS TESTS

Particle size (μm)[a]	Wind speed (km/hr) 2	8	24
5 ± 0.5	ℓ	ℓ	ℓ
7 ± 0.5	ℓ	ℓ	ℓ
10 ± 0.5	ℓ	ℓ	ℓ
14 ± 1.0	ℓ	ℓ	ℓ
20 ± 1.0	ℓ	ℓ/s	ℓ/s

[a] Mass median aerodynamic diameter

ℓ = liquid particle

s = solid particle

Number of liquid particle test points (minimum of 3 replicates for each combination of wind speed and particle size): 45

Number of solid particle tests (minimum of 3 replicates): 6

Total number of test points: 51

THE APPLICATION OF FABRIC FILTERS TO HOT METAL DESULFURIZATION PROCESSES USING SALT COATED MAGNESIUM

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ABSTRACT

The application of fabric filters to molten iron (hot metal) desulfurization at two of the Armco Inc. facilities has created a number of challenges and problems. The dust collected by the baghouses is both cementitious and hygroscopic due to the presence of magnesium oxide and chlorides that are generated when salt coated magnesium is injected into the hot metal. Various approaches and techniques have been and are currently being employed to deal with high operating pressure drops, excessive pressure-drop rise rates, and short bag life due to permanent surface blinding. The unsatisfactory performance of the existing systems prompted an installation of a pilot baghouse at one site to evaluate various design parameters to be used in correcting the existing problems and expanding the system to allow for increased production levels. This paper discusses both the failures and successes experienced in dealing with this problem.

I. SUMMARY

The use of salt-coated magnesium in hot metal (iron) desulfurization can pose significant problems with respect to the application of fabric filters. This paper discusses the successes and failures of Armco's experiences at its Ashland and Middletown Works facilities in dealing with these problems.

A number of pilot unit and full-scale evaluations of pulse jet baghouses led to the following conclusions:

(1) The design air-to-cloth ratio should not exceed 4.0:1 fpm.

(2) Modular construction should be employed to allow for off-line cleaning and high pressure-drop rise rates.

(3) A clean, dry supply of 110-120 psig compressed air is needed to provide adequate cleaning energy. The cleaning cycle must include between 4-7 pulses for each bag to stabilize the baseline pressure drop.

(4) To minimize the creation of cementitious magnesium hydroxide in the permanent bag cake, temperature control is needed.

II. INTRODUCTION

Armco Inc. has been operating hot metal desulfurization processes at both the Ashland and Middletown Works basic oxygen shops since 1978.

The Armco systems are constructed in a manner that allows for the injection of a nitrogen carrier gas and sulfur reactant material such as lime, magnesium, or calcium carbide into a hot metal torpedo car. Two identical lance stations are provided at the process locations.

The injection material that was initially used was a blend of lime and magnesium, but in 1980 a decision to use 100% salt-coated magnesium was made. The emissions characteristics were altered substantially and as a result the performance of the baghouses declined significantly.

After conversion to salt-coated Mg, the baghouse pressure drops ran consistently above 10 inches of water and frequent bag changes became a part of the normal routine. The poor performance of the systems created difficulty in complying with air regulations compliance problems and the work environment at the desulfurizer station deteriorated.

A number of fabric filter and bag vendors were called upon for advice and consultation over a two-year period. Bags of various types were installed at the Middletown and Ashland locations including singed polyester, glazed polyester, latex coated polyester, and PTFE laminated fabric.

Performance of each bag type investigated would begin with a reasonable baseline pressure drop and gradually increase to a point where the bags would have to be replaced. The longest that an acceptable operating level was maintained was approximately eight weeks.

The first and most substantial improvement in performance was achieved when the systems were periodically cleaned off-line. Baseline pressure drops at Middletown decreased from 10" W.C. to 6" W.C. immediately. This indicated that a high level of reentrainment was occurring.

The compressed air pressure was operating over a 65-80 psi range and it was felt that a higher pressure would be helpful. Installation of a new dedicated compressor at Ashland allowed for a compressed air pressure increase to 110 psi. The baseline pressure drop decreased from 11.5 inches W.C. to 8.5 inches W.C. instantaneously.

Based upon tests at Middletown and Ashland, the systems were modified to provide off-line cleaning and higher compressed air pressure. Increased bag life and improved performance were realized, but satisfactory performance was still not obtained. The rate of the pressure drop rise was found to be too high for the off-line cleaning requirements. The Δp rise rate would at times average about 1" W.C. per minute which allowed only a single operating period before off-line cleaning would be required. It was at this point that the decision to conduct a pilot baghouse study was made as it was clear that the existing systems would be unable to perform acceptably.

The purpose of the pilot unit program was to provide a basis for selecting design parameters that could be used in modifying the control systems in a manner that would provide for acceptable performance. A pilot baghouse program was planned and approved for the Ashland Works.

In the interim, the existing system performance was monitored with a number of new operating and maintenance techniques employed. The bag life was extended from eight weeks to six months by paying close attention to operating techniques and improved maintenance procedures, including:

- Cleaning off-line between every operating period and during extended downtimes.

- Eliminating hopper in-leakage points and improved discharge handling procedures.

- Improving pulse jet air valve maintenance.

- Assuring proper bag sizing and eliminating downsized replacement bags.

- Minimizing the level of hopper dust buildup allowed.

At this point a series of events resulted in a change in tactics at the Middletown Works. Production requirements increased the need to correct the existing problems and expand the system capacity. Closure of the Houston Works also made available a used sinter plant baghouse system that was compatible with the existing system.

Ashland management chose to continue the pilot unit strategy and the unit was installed and became operational in December o 1983.

III. SYSTEM DESCRIPTIONS

Ashland

The desulfurization system at Ashland is elevated above the train track near the hot metal transfer station at the basic oxygen shop. Dual stations are arranged in a tandem fashion over a single track. The torpedo cars are placed under the permanently mounted hoods that are constructed for a close fit. The injection lance extends vertically downward through the hoods and into the hot metal bath as the salt-coated magnesium is blown into the hot metal with a nitrogen gas. The emissions are captured by the hood and side drafted into the station duct and then into the main duct where they are conveyed to the baghouse. Guillotine dampers installed adjacent to the hoods are used to isolate the desired station for use. The normal operating procedure involves closing both dampers when the unit is in a standby mode and additionally shutting down the fan for extended non-operating periods. It is during these periods that the baghouse is cleaned.

The pulse jet baghouse is a Flex-Kleen Model #100 WM-600 type that contains 600 5-3/4" x 102-1/2" singed polyester bags. The fan is sized for 40,000 scfm and 19 in. H_2O static pressure producing an air-to-cloth ratio of approximately 6.0:1 fpm. A temperature protection system has been installed that provides for the opening of the inactive hood damper if duct temperatures exceed 250°F.

Middletown

The Middletown system is elevated above a parallel train rail configuration and is remote from the basic oxygen shop. The hoods are constructed in a permanently mounted close-fit manner with a side draft style of ducting. Salt-coated magnesium and nitrogen carrier gas are injected into the hot metal in the torpedo cars and the emissions are transported through ductwork to the baghouse. Normal operating procedures involve a shutdown of the fan for off-line cleaning whenever the production schedule allows. Whenever idle torpedo cars are parked under the hoods the baghouse system remains on-line to remove fumes from the hot metal. Butterfly dampers in the duct adjacent to the hoods provide for isolation of the individual stations.

The baghouse is a Standard-Havens Alpha/Mark III reverse pulse unit designed for 40,000 acfm at 125°F and an air-to-cloth ratio of 5.93:1 fpm. There are 294 singed polyester bags installed in the unit along with wire-mesh cages.

Ashland Pilot Unit

A modified nine bag bin-vent baghouse manufactured by Flex-Kleen was installed at the desulfurizer during the fall of 1983. The gas flow was sidestreamed using a 6" round pipe. The pipe was positioned in the center of the main 3' x 3' duct beyond the last 90° turn prior to the baghouse transition.

Isolation of the pilot unit was achieved by installing an air operated butterfly valve in the inlet pipe to the baghouse. This valve was controlled by two parameters: (1) pressure drop across the pilot unit and (2) static pressure in the main baghouse. If the pressure drop reached a predetermined set point the pilot unit fan would shut down, the inlet damper would close, and a timed cleaning cycle would occur. In situations where cleaning wasn't warranted with the main system in a standby mode, the low static pressure in the main system would activate a pressure switch and cause the inlet damper to shut. Shutting and sealing of the damper prevented a back-flow from occurring in the pilot unit due to slight undersizing [illegible] the fan.

Installed in the outlet duct of the pilot unit were a thermocouple for temperature measurement and an orifice plate for flow measurement. The values were recorded along with the baghouse pressure drop on a continuous strip chart recorder for later data reduction.

A variable position butterfly damper on the fan outlet was used to vary the gas flow to the system.

The dust was discharged into a 55-gallon drum from a pyramid hopper equipped with a slide gate damper and the drum was sealed with a lid and hose connections to prevent in-leakage. The drum was checked periodically for dust level measurement and sampling.

IV. PROGRAM PLAN

The pilot unit program plan was oriented toward providing engineering data necessary for evaluating various design approaches.

The first major parameter of interest was the air-to-cloth ratio. The high baseline and maximum bag pressure drops that were being encountered in the existing systems created suspicion that an A/C ratio of 6.0:1 fpm was too high for this application. A program to evaluate A/C ratios in a range from 2:1 to 6:1 was established. Each level was allowed to stabilize before the A/C ratio was changed.

In conjunction with the A/C ratio, the pressure drop rise rate was evaluated. The pressure drop rise rate is defined as the rate at which the bag pressure drop rises as a function of time and is usually expressed in inches of water per minute. This rate relates to the amount of on-line filtering time that can be achieved before cleaning must occur.

Selection of a cloth type to be used during the air-to-cloth studies involved discussions and evaluations with many vendors and industry contacts. Armco experiences with the various types of bags indicated that the problems being encountered could not be solved with a simple bag change-over. It was decided to use a basic singed polyester bag instead of a more expensive treated or coated bag as this type of bag is used extensively in the industry. The nature of the dust being filtered tended to indicate that the advantages of the more expensive fabrics were overcome by the tenaciousness of the dust.

After completing the A/C ratio studies, a cleaning system study was performed. The purpose was to establish the cleaning cycle characteristics that could be expected within the most likely design A/C range.

Parallel with the pilot unit studies, lab scale evaluations were on-going to define the dust characteristics. Specifically, experience has shown that the longer the bags remain in service, the more severe the blinding becomes. Large dust nodules form on the bag surfaces over time and the transformation appears to occur within variable time ranges.

Data Handling

In addition to the data recorded on the strip chart recorder with respect to temperature, pressure drop, and flow, a record of the amount of dust collected and operational status notes were kept.

All the data obtained was compiled on Apple computer discs for processing, performing calculations, and creating a main data disc file. The main data disc file was then entered into an IBM main frame via Armco Research's Hewlett-Packard. A SASS software package provided the means for analyzing the copious quantities of data points that were generated.

The strip chart is removed from the pilot unit and entered into a data file using a graphics tablet. The graphics tablet program allowed the beginning and ending parameters for each magnesium blowing period to be entered by just touching the corresponding points on the strip chart with the tablet pen. An 8-hour period is placed on the tablet and the data entered. The time, month, and day were also automatically entered into the data set.

Another raw data file was created based upon daily information with regard to weather and the amount of dust collected in the drum. This file was constructed by entering the individual bits of data manually with a user-friendly program.

Both of the raw data files were subsequently used for creating a main data file. An Apple basic program written in-house performs a number of calculations and cross-matches the raw data into the main data file. The main data file is then transmitted to the IBM main frame and the appropriate SASS program functions are performed.

Data Analysis

The analysis of the performance of the pilot unit involved categorizing the various parameters into dependent and independent variables. The following classifications were made:

Dependent	Independent
Maximum pressure drop	Accumulated operating time on bags
Baseline pressure drop	Average gas temperature
Pressure drop rise	Average air-to-cloth ratio
	Average emission rate
	Pulse jet air pressure
	Ambient air temperature
	Ambient humidity
	Wind speed
	Wind direction

Each dependent variable was plotted against each of the independent variables to identify obvious correlations that could be used in providing design information. The strongest correlations were found to occur with respect to baseline pressure drop and:

Accumulated operating time on the bags
Average air-to-cloth ratio
Pulse jet air pressure

The pressure-drop rise rate versus air-to-cloth ratio plot also showed a strong correlation.

An evaluation of the plot (Figure 1) of baseline pressure drop versus accumulated time on bags indicated that the baseline pressure drop did not show any signs of leveling out over time. A continuous rise in the baseline pressure drop from 1.0" H_2O to 7.0" H_2O was found to occur over the study period. This tended to confirm and parallel the performance of the full-scale baghouses operating at Middletown and Ashland. Observation of the permanent dust cake buildup showed that the density of nodule formation increased consistently throughout the study period.

Plotting of the baseline pressure drop versus air-to-cloth ratio (Figure 2) was done at different time periods to account for the continuously rising baseline pressure drop and the results were evaluated. As can be seen, the effect on the P was dramatic at an A/C range of 3.5-4.0:1 fpm. At this A/C the slope of the line rises very rapidly as compared to a lower A/C ratio.

The pressure drop rise rate versus air-to-cloth ratio plots (Figure 3) revealed that the average rates increased at a reasonable rate as the A/C ratio increased but the maximum rates that were encountered were significantly affected. Between A/C ratios of 2.0:1 and 5.0:1 the average rates increased approximately 100%, but the maximum rates increased 360%.

When the baseline pressure drop was plotted against the pulse jet air pressure data, a decidedly downward slope of the curve was found to exist as the air pressure increased (Figure 4). This tends to confirm earlier observations made when increased air pressure tests were performed at Middletown and Ashland. Those tests showed an instantaneous reduction in the baseline of from 2.5 to 3.0 inches of water when the compressed air was increased from 80 to 110 psi.

The effect of average gas temperature, average emission rate, ambient air temperature, ambient humidity, wind speed, and wind direction on pressure drop and the pressure drop rise rate was not significant. It is hypothesized that the range of the average emission rate encountered during the study was not large enough to effect a difference.

Dust samples from the baghouse discharge were obtained on a regular basis and chemical analysis was performed by Armco's Research Department. The analysis also included moisture analysis and density determinations. The ranges for the analysis are given below:

Density	20.9-32.5 lbs/ft^3
H_2O	0.99-2.2%
Carbon	7.3-53%
Sulfur	0.99-1.27%
Sodium Chloride	0.85-k0.92%
Potassium Chloride	1.5-3.4%
Calcium	1.3-2.5%
Magnesium Oxide	20.2-28.5%
Iron	12.0-16.9%
Manganese	0.4-0.8%
Silicon Dioxide	1.8-2.2%

In addition to the dust analysis on the discharge, an analysis of water content of the nodules that were forming on the bags was performed. The dust discharge showed a moisture content of 1.8% and the permanent cake (nodules) had a moisture content of 4.5%, an increase of 2.7%. The dust from the discharge was considered to be recently deposited and the permanent cake and nodules were considered to have been exposed to the gas stream for a long period of time. This data indicated that a moisture buildup in the dust was occurring and tests indicated that the MgO was being converted to $Mg(OH)_2$ -- a cementitious material.

It is also theorized that the cyclic heating and cooling of the baghouse contributes to an increase in the conversion rate. The baghouse cools down between injection periods allowing the salts to pick up ambient moisture along with moisture condensation. The reheating process during the next injection causes the moisture to begin vaporizing and increases the partial pressure in the dust cake. The additional heat and the increase in partial pressure increase the rate of reaction of MgO to $Mg(OH)_2$ in the presence of water.

V. RESULTS AND CONCLUSIONS

The most important design information extracted from the pilot unit program is that a critical air-to-cloth ratio is present between 3.5-4.0:1 fpm and a severe pressure drop penalty results when this range is exceeded. Both the Middletown and Ashland facilities are operating close to 6.0:1 fpm, partially explaining the problems that we have encountered attempting to achieve satisfactory operation of the baghouses.

The pressure drop rise rate appears to vary directly with the air-to-cloth ratio. Average Δp rise rates can be significantly different from the maximum rates encountered, probably due to operating variations in the process. Since this directly affects the time available before the maximum allowable pressure drop is reached, system design must include allowances for this parameter. This is especially critical if adequate off-line cleaning periods are not available due to production demands. To assure that this time is available under the more severe operating conditions, the maximum Δp rise rates should be employed. Both of Armco's desulfurizer baghouses are single modules that were designed as on-line cleaning units. Production schedules generally do not allow off-line cleaning to be used between every injection period. The most obvious design approach to deal with these conditions is to construct a multiple module baghouse system with off-line cleaning capabilities.

Tests performed on the full-scale system and the pilot unit indicate that increasing the pulse jet air pressure results in lower baseline pressure drops. The relationship seems to be direct and immediate when a system that has been operating in the 60-80 psi range is provided with 110 psi air. A properly designed desulfurizer baghouse would apparently include a compressed air system that can provide clean, dry air at a pressure of 110-120 psi. The number of cleaning cycles required to achieve reasonable stability in the baseline pressure drop appears to be in the range of 4-7 when 110 psi air pressure is provided.

The conversion of MgO to $Mg(OH)_2$ in the dust complicates the use of fabric filtration considerably. The dust takes on a cementitious quality over time due to the cyclic heating and cooling of the baghouse. As the dust becomes cementitious, surface blinding of the bags worsens until a bag change is required. Retarding the conversion rate of the dust is probably the best that can be expected. However, if the bag life can be extended to one year instead of the existing 2-3 months, the difference in performance and maintenance costs would be considered substantial.

Since the presence of moisture and heat both contribute to an increase in the conversion rate, elimination or control of these factors is desired. The best compromise situation would be one where the temperature is always a few degrees above the dew point. For a desulfurization baghouse system, temperature control would require the use of a clean-fuel burner system on the inlet side of the baghouse.

The Middletown Works facility is currently undergoing expansion and modification to provide a system that will operate based on the experiences at both the existing baghouses and the pilot unit baghouse. Production requirements are such that the new system must process more than twice as much air as the existing unit. The new system will process from 50,000 to 90,000 acfm and operate in an air-to-cloth ratio range from 2.7 to 4.1:1 fpm. There will be a total of four (4) modules that provide an operating system with off-line cleaning capability. A new compressor will provide a clean, dry supply of 110 psi pulse jet air to each module. The cleaning cycles will be activated when the baghouse pressure drop reaches 10" w.c. and each bag will be cleaned five times before the module is brought back on-line. Supplemental heating will not be provided initially, but the duct design will be such that a burner system can be installed at a later date.

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JOB NO.
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BY Rodney A. Gibson

FIGURE 1. PLOT OF BASELINE PRESSURE DROP vs. ACCUMULATED OPERATING TIME ON BAGS.

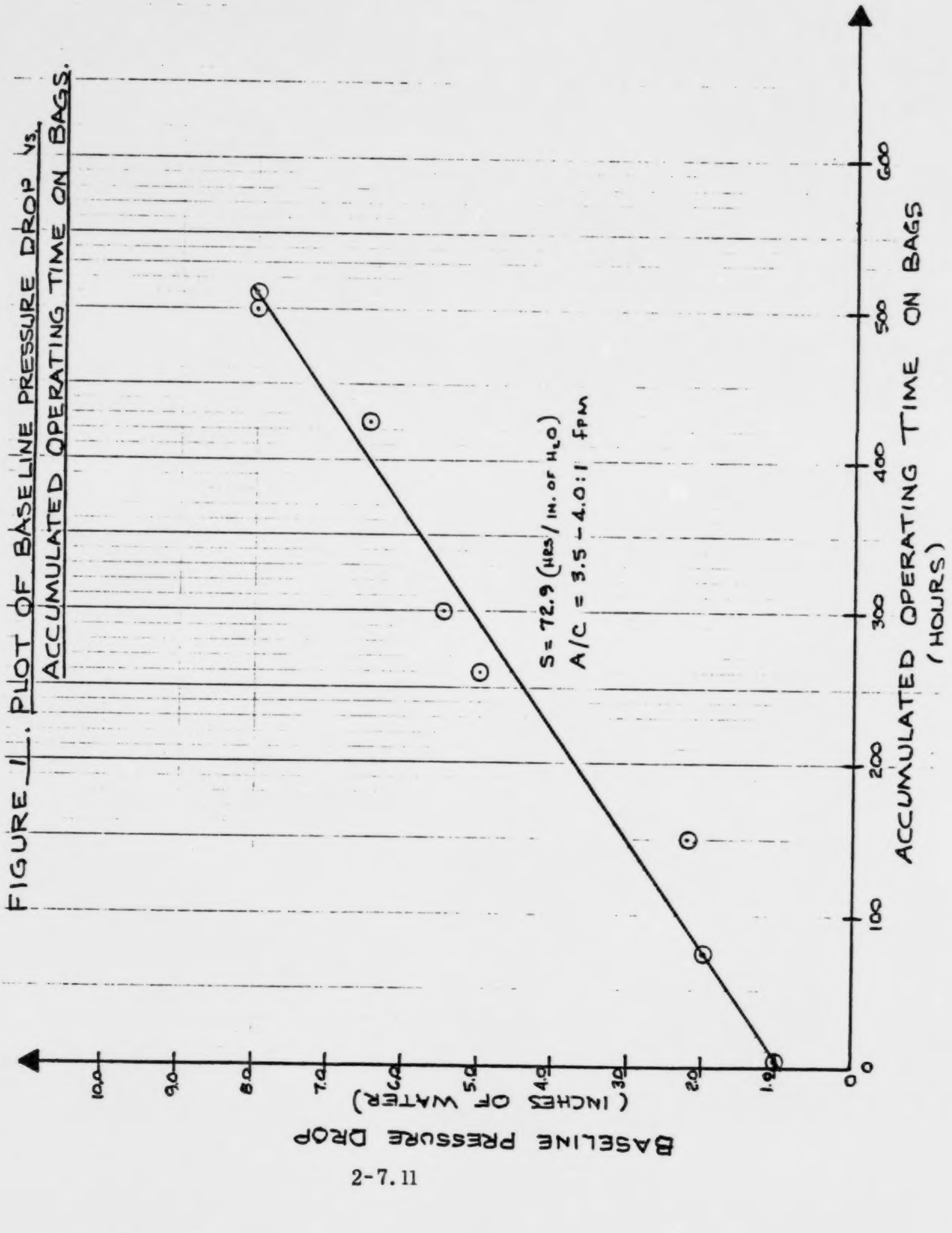

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FIGURE 2 PLOT OF BASELINE PRESSURE DROP VS. AIR-TO-CLOTH RATIO

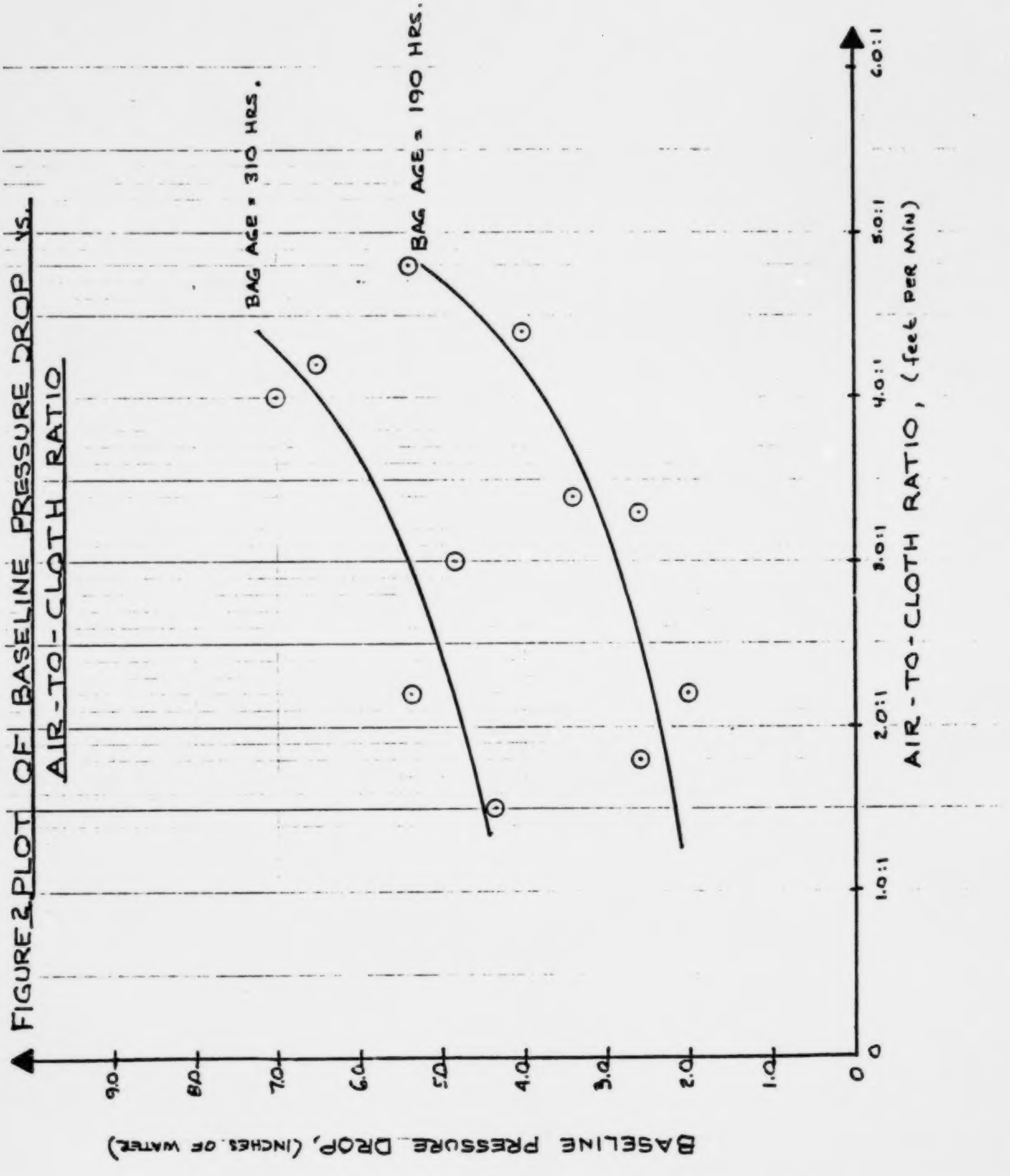

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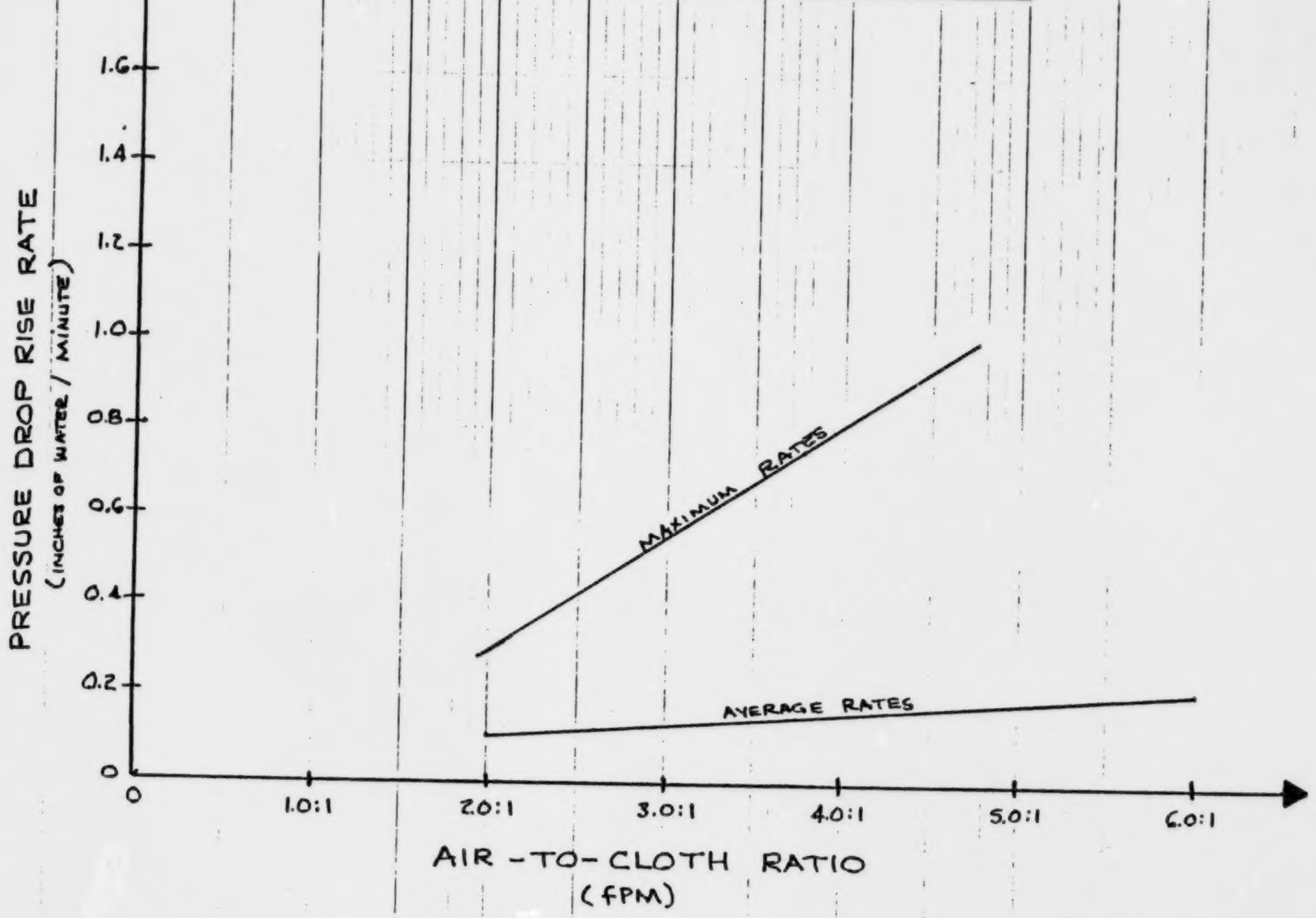
FIGURE 3. PLOT OF PRESSURE DROP RISE RATE VS. AIR-TO-CLOTH RATIO



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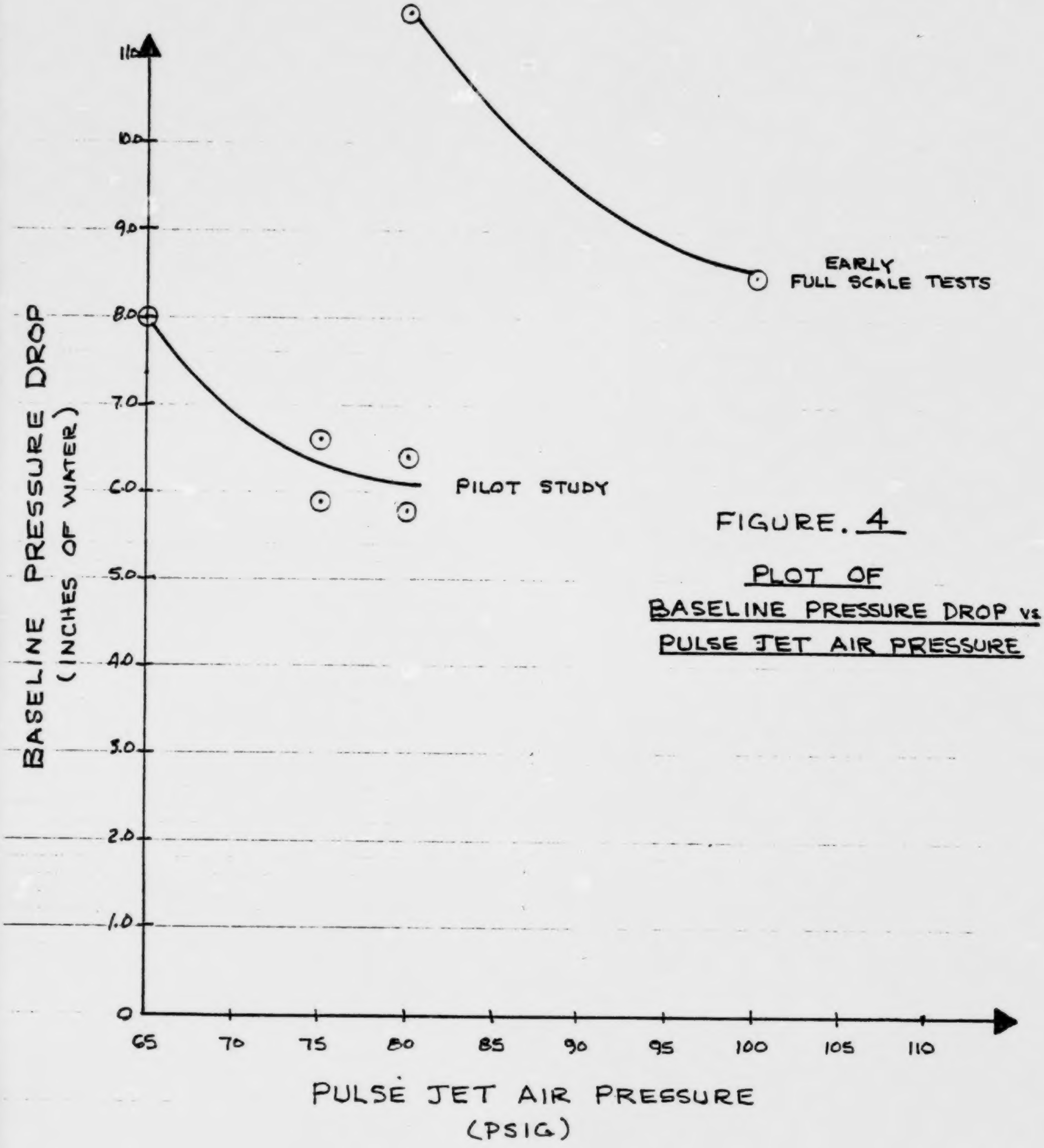

FIGURE. 4

PLOT OF
BASELINE PRESSURE DROP vs
PULSE JET AIR PRESSURE

A STUDY OF ELECTRIC STEELPLANT BAGHOUSE FILTRATION

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ABSTRACT

This paper reports a major study conducted into fabric filtration at a working baghouse providing gas cleaning for combined primary and secondary fume extraction at an electric arc furnace steelmaking plant. The objectives of the research were to investigate different filter media (to determine their performance and suitability for this type of application) and to study baghouse operation in order to optimise it.

The practical aspects of the study included substantial modifications to one compartment of an existing baghouse whereby it could be operated and cleaned independently using permutations of various control parameters. Additionally, a comprehensive system of monitoring instrumentation was installed to record all relevant parameters.

Four different filter media were examined - woven heavy duty terylene (teased on the collecting side), seamless knitted polyester, polyester needlefelt and PTFE-laminated polyester felt. The results obtained are compared for different cleaning methods (shaking, reverse air and combined shaking/reverse air), paying particular attention to power requirements, and hence likely operating costs.

INTRODUCTION

With improved standards of fume control, many large bag filter houses have been built to collect secondary fume arising in electric arc furnace steelmaking plants. In some cases, the primary and secondary fume extraction systems are combined before cleaning in such a filter. These bag filter plants have high operating costs, which are governed largely by the pressure drop across the filter bags which in turn is influenced by the type of filter medium and the method of bag cleaning employed. A recent examination of the British Steel Corporation's major electric arc melting shops in the Sheffield area has shown that power costs to run the fume extraction and cleaning systems range from 0.33 to 1.08 £/t of liquid steel. In addition, there are maintenance and parts replacement costs.

Thus, there are both environmental and financial incentives to instal the most appropriate fume cleaning plants and to operate these effectively and economically. There are difficulties in extrapolating the results of laboratory and pilot scale studies to a full scale plant, and this paper describes extensive experimental studies which have been carried out on a full scale operating baghouse using virgin dust. The intention was to gain both practical experience and data of direct relevance and immediate applicability to existing installations. It was also intended to provide guidance for the design and selection of filtration media and operational aspects of new bag filter plants.

The experimental work was based largely at BSC's Templeborough Melting Shop in Rotherham, where half of one compartment of a shaker-type baghouse was modified and fully instrumented for the purposes of the study. Four different types of filter medium were studied under a range of operating conditions, which included alternative bag cleaning methods (shaking, reverse air and combined shaking/reverse air). During the course of the work, major operational changes occurred at Templeborough, which had an influence on the duty required of the filter and hence on the details of the work conducted and results obtained. Some parallel, but more restricted investigations have taken place at the baghouse serving BSC's Aldwarke Melting Shop and some of the results obtained there are included in the paper.

GAS CLEANING SYSTEM AT TEMPLEBOROUGH

INITIAL SITUATIONS

The fume extraction plant was commissioned in August 1975 with 11 compartments filtering fume from roof hoods over 4 x 180 t arc furnaces and associated ladle pits. The baghouse was extended in two stages to 17 compartments in order to accommodate directly extracted fume from 3 of the 4 furnaces, but by the time this study began in June 1981, the Melting Shop had been reduced to the use of one furnace only, with the fume cleaning plant filtering fume from the direct extraction and the roof hoods over the furnace and casting pit. The specification of the plant is given in Table 1.

MODIFICATIONS FOR THE STUDY

The end compartment (No. 17) was chosen as the most convenient for the study, and extensive modifications were made to the compartment so that it could be operated independently of the rest of the baghouse. To reduce somewhat both the scale and cost of the study, only one half of the compartment was utilised. The more important modifications made are described below.

Ventilator

Vertical sheeting was inserted along the length of the ventilator to divide it in two, and a stack was added over the test half compartment, together with test platform, electrical supplies, etc.

The Compartment

The vertical sheeting described above was extended down through the compartment and other work was carried out to ensure that the test half compartment was fully separate from adjacent parts of the baghouse.

Hopper System

The existing hopper and conveyor system for handling the dust removed from the bags required major alterations so that dust filtered by the test half compartment could be treated separately. An extra screw feeder was fitted which transferred dust to a 5 t capacity hopper at ground level. This hopper was fitted with load cells enabling the dust discharged to be accurately weighed on a continuous basis.

Reverse Air Fan and Ductwork

To enable reverse air cleaning to be carried out, a completely new reverse air system was installed into the test half compartment. A radial bladed fan was used, capable of extracting a maximum of 30 m^3/s of air at 30 °C against a system resistance of 40 mbar. This fan drew air through the test half compartment in the reverse direction to normal flow, the full system comprising additional ductwork and associated valves. Dust build-up on the fan blades caused some out of balance

TABLE 1. SPECIFICATION OF THE TEMPLEBOROUGH BAGHOUSE AT COMMENCEMENT OF STUDY

Number of Compartments	17
Number of bags per compartment	672
Bag dimensions	6.7m long x 0.2m dia.
Filter type	Pressurised, one compartment off for cleaning
Cleaning method	Shaking
Total cloth area	48,092m^2
Total maximum design flow	830m^3/s
Filtering velocity	1.1m/min, assuming one compartment off for cleaning
Number of fans	5 (3 operating)
Power on fan shaft	1104kW at 72°C
Fan Speed	740 rpm
Volume control	Fan inlet louvre dampers and total fan current limiting device

problems and a vibration monitor was fitted to the fan bearing to avoid serious situations developing.

Compartment Cleaning Control Unit

To operate the test half compartment independently of the main filter a separate control unit was installed, incorporating a GEM80 programmable controller. This enabled the parameters defining the cleaning sequence to be varied over a wide range of settings.

INSTRUMENTATION AND DATA-LOGGING

Operational and performance parameters associated with the test half compartment were monitored throughout the trials conducted. Table 2 indicates in general terms the measurement techniques used; the signals from the instruments were relayed to equipment housed in a mobile laboratory at ground level close to the baghouse. This included a data-logging system linked to a digital cassette recorder on which was recorded five minute-average values of the parameters being measured. The tapes were subsequently processed on a mini computer, which provided both tabulated and graphical presentation of the data.

SELECTION OF FILTER MATERIALS FOR TESTING

During the time available in the study, it was possible to test four different types of filter medium. In arriving at the final choice, due consideration was given to the experience of and reports from other users (1, 2, 3) and discussions were held with LECES in France and BFI in the Federal Republic of Germany. A survey was also made of the filter fabrics used in other electric arc furnace baghouse installations around the world. The following 4 filter types were selected:

FABRIC 1

A heavy duty, woven terylene material, napped on the collecting surface, and the medium originally installed in the baghouse at Templeborough and Aldwarke.

FABRIC 2

A lightweight seamless polyester fabric, of knitted construction which had received favourable reports from a Canadian installation.

FABRIC 3

A polyester needlefelt material with a singed surface on the collecting side. There is increasing interest and application of needlefelts in Europe.

TABLE 2. MONITORED PARAMETERS AND METHODS OF MEASUREMENT

PARAMETER	MEASUREMENT EQUIPMENT	SIGNAL CONDITIONING	RANGE IN ENGINEERING UNITS
Total waste gas velocity	Static Pressure probes calibrated via pitot tube	Pressure transducer	0 - 500m^3/s
Waste gas temperature	Integral sheathed thermocouple	Thermocouple lineariser	0 - 125°C
Inlet dust loading	Obscuration meter[a]	Continuous averaging filters	0 - 10g/m^3
Compartment gas flow	Anemometer	Rectifiers	0 - 35m^3/s
Compartment gas temperature	Integral sheated thermocouple	Thermocouple lineariser	0 - 125°C
Pressure drop across filter bags	Static pressure probes	Pressure transducer	0 - 36.8 mbar
Reverse air flow	Static pressure probes calibrated via pitot tube	Pressure transducer	0 - 28m^3/s
Ambient air temperature	Integral sheathed thermocouple	Thermocouple lineariser	0 - 125°C
Outlet dust loading	Krohne-Beta dust monitor	Parallel BCD	0 - 2mg/m^3
Integrated weight of dust collected	Hopper load cells	Parallel BCD	0 - 5000kg

[a] This instrument has been developed by British Steel Corporation, Swinden Laboratories

FABRIC 4

An expanded PTFE membrane supported on a polyester felt laminate ("Goretex"). Impressive performance claims had been made for this high cost medium of unique construction.

Basic details of the four materials are given in Table 3.

TESTING PROGRAMME

BASIC APPROACH

The test half compartment was fitted with bags of the fabric under test. These were accurately tensioned and conditioned if necessary and then submitted to a series of test runs, each of which lasted for a maximum period of one week. Each test run studied a particular cleaning method - shaking, reverse air or combined shaking/reverse air - under controlled cleaning conditions while the half compartment filtered fume from the electric arc furnace direct extraction and roof hood systems. Parameters were varied over the following ranges:

Frequency of cleaning by shaking	15 - 300 min
Duration of shake	0 - 75 s
Frequency of cleaning by reverse air	30 - 150 min
Duration of reverse air	20 - 60 s
Quantity of reverse air	5 - 30 m^3/s

During each test, continuous measurements and recording of parameters listed in Table 2 were carried out along with regular engineering checks on baghouse hardware. At the end of each test week, selected bags were weighed to determine the extent of dust retention and others were examined, before cleaning, to determine the distribution of dust collected along the length of the bag. Bags were fitted with anti-collapse rings before commencing any reverse air cleaning trials.

TESTS COMPLETED

At the outset of the study, it was intended to conduct tests for a period of 20 weeks on each filter medium examined. Because the work was based at an operating steel plant, there were inevitable delays and other production factors which interfered with the planned programme; additionally some problems were experienced in operating the test half compartment and its associated instrumentation. The number of test weeks completed varied from 14 for Fabric 1 to 29 for Fabric 4.

TABLE 3

SPECIFICATION OF FILTER FABRICS TESTED

	FABRIC 1	FABRIC 2	FABRIC 3	FABRIC 4
Supplier	Tilghman Wheelabrator	Highcron Industrial Filters	Heath Filtration	W. L. Gore & Associates
Material	Heavy duty Terylene	Combination filament and spun polyester	Polyester felt with singed collecting surface	Goretex PTFE membrane laminated to Polyester felt
Material Code		RTO2	Zephron 340PE	Goretex 4319
Weight (g/m^2)	472	356	340	407
Thickness		0.56mm	1.50mm	
Permeability (as new) ($ml/cm^2.s$ at 0.98mbar)	14 - 20	10 - 18	18 - 26	3.2 - 4.1
Working Temperature	135°C max	135°C max	160°C max	135°C max
Mullen Burst	-	1895kN/m^2	-	2069kN/m^2
Cost per Bag (January 1981 prices)	£19	£9	£9	£48

RESULTS AND DISCUSSION

INITIAL COMMENTS

A basic objective of this study was to compare the performance and characteristics of the different filter media tested. Reference has just been made to general problems which interrupted or forced changes to the programme, and one consequence of these is an incomplete collection of test results. However, there were other factors which had a much more direct influence on the comparability of the results obtained.

The most dramatic change has been the steady increase in inlet dust loading presented to the baghouse. There has been an increasing trend towards the feeding of dusty materials and the use of lower grades of scrap and these have pushed up the inlet dust loading from 9 g/s at the start of the study to 30 g/s at the end. Clearly, the duty demanded from bags made of Fabric 1 was significantly different from those made of Fabric 4.

Initially, it was assumed that the remaining compartments on stream (i.e. those other than the test half compartment) would provide a stable base against which the test results could be viewed. To some extent this was the case, but occasionally major changes occurred in the other compartments which affected the results from the test half compartment.

There is insufficient space here to detail all the results obtained. These are available, however, from the authors. Data particularly relevant to the discussion are, however, presented graphically or in Tables.

DUST LOADING AND CLEANING EFFICIENCIES

Cleaning efficiencies were calculated using the formula:

$$\left(\frac{\text{Mean inlet dust loading - mean outlet dust loading}}{\text{mean inlet dust loading}}\right) \times 100\%$$

With one exception, all the fabrics tested under each mode of cleaning gave cleaning efficiencies of 99.92% or better, equivalent to mean outlet dust loadings of less than 1 mg/m^3 stp for the range of inlet loadings experienced (360 - 1200 mg/m^3 stp). The exception was Fabric 3 (polyester needlefelt) under combined shaking/reverse air cleaning, where the efficiency fell to 99.67%, equivalent to a mean outlet dust loading of 2.4 mg/m^3. From these results there is little to choose between the dust arrestment capabilities of the different media.

DUST DISTRIBUTION AND RETENTION

Table 4 summarises the results obtained from the weighing of a selected sample of bags at the end of each test week. The dust distribution figures relate to bags immediately before cleaning, and show how the dust collected is distributed between the top, middle and bottom thirds of the bags. No data are given for Fabric 4 (Goretex) because experience showed that simply touching the bags resulted in the dust being removed prematurely before any weighing could commence.

Apart from the shaker tests on Fabric 1, where dust was evenly distributed along the length of the bag, the results show more dust to be deposited at the bottom of the bags, with the least at the top. The shape and dimensions of filter bags may be an area worthy of further study to obtain a more even distribution of collected dust.

Also given in Table 4 are mean values for the weight of dust retained per bag after the cleaning cycle. The residual cake associated with Fabric 1 was generally much greater than for the other three fabrics; this is consistent with problems experienced. For the worst situation, in excess of 7 t of dust remained adhered to these bags in the half compartment. Frequent mechanical failures of the shaking mechanisms occurred, and fractures of the beams supporting the bags has also taken place.

The residual dust load for Fabric 4 (Goretex) was less than almost all of those recorded for the other fabrics. Results from the Aldwarke baghouse, where the different method of bag suspension results in an improved shake, indicate that figures as low as about 1 kg per bag can be obtained.

FLOW-PRESSURE RELATIONSHIPS

Figure 1 is a plot of all the test compartment gas flow and pressure drop data obtained in a typical test week. There is a considerable amount of scatter in the data, resulting partly because the logged values were taken at various times during the on-stream condition of the test compartment and there would therefore be a variable dust cake adhering to the bags. It should be noted that, because all the compartments in the baghouse are fed from a common manifold system, the pressure drop across the test compartment at any time was governed largely by the situation pertaining in the other 16 compartments.

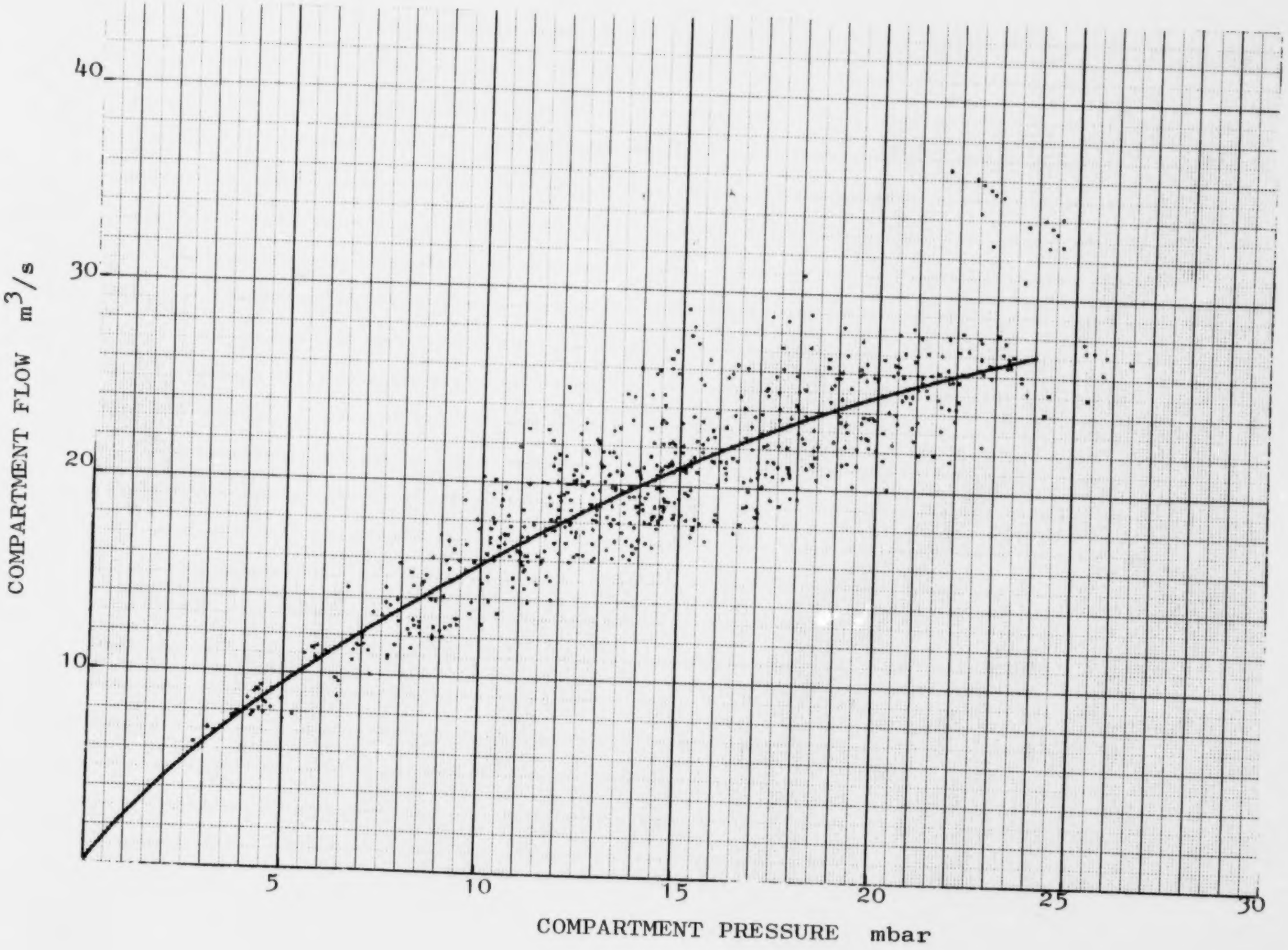
To enable a clearer comparison to be made between different fabrics and cleaning methods, the values of the flows measured for a given pressure drop were averaged and these averaged data plotted against pressure drop. Figure 2 shows examples of the

TABLE 4

DUST DISTRIBUTION AND RETENTION BY WEIGHING

MATERIAL	CLEANING MODE	MEAN DUST DISTRIBUTION %			MEAN WEIGHT OF DUST IN BAG AFTER CLEAN kg
		TOP	MIDDLE	BOTTOM	
1. Tilghman Wheelabrator Heavy Duty Terylene	Shake	34.2	31.4	34.4	7.42
	Reverse Air	23.3	36.4	40.3	12.98
	Combined	-	-	-	7.11
2. Highcron Seamless Polyester	Shake	22.7	35.6	41.7	2.81
	Reverse Air	18.0	32.8	49.2	3.68
	Combined	26.7	35.4	37.9	1.99
3. Zephron Polyester Needlefelt	Shake	18.9	39.9	41.2	3.14
	Reverse Air	23.8	27.6	48.6	7.56
	Combined	-	-	-	3.69
4. Goretex PTFE Membrane	Shake	-	-	-	2.59
	Reverse Air	-	-	-	-
	Combined	-	-	-	-

FIGURE 1. EXAMPLE PLOT OF COMPARTMENT FLOW - PRESSURE DROP RESULTS FOR A TEST RUN.



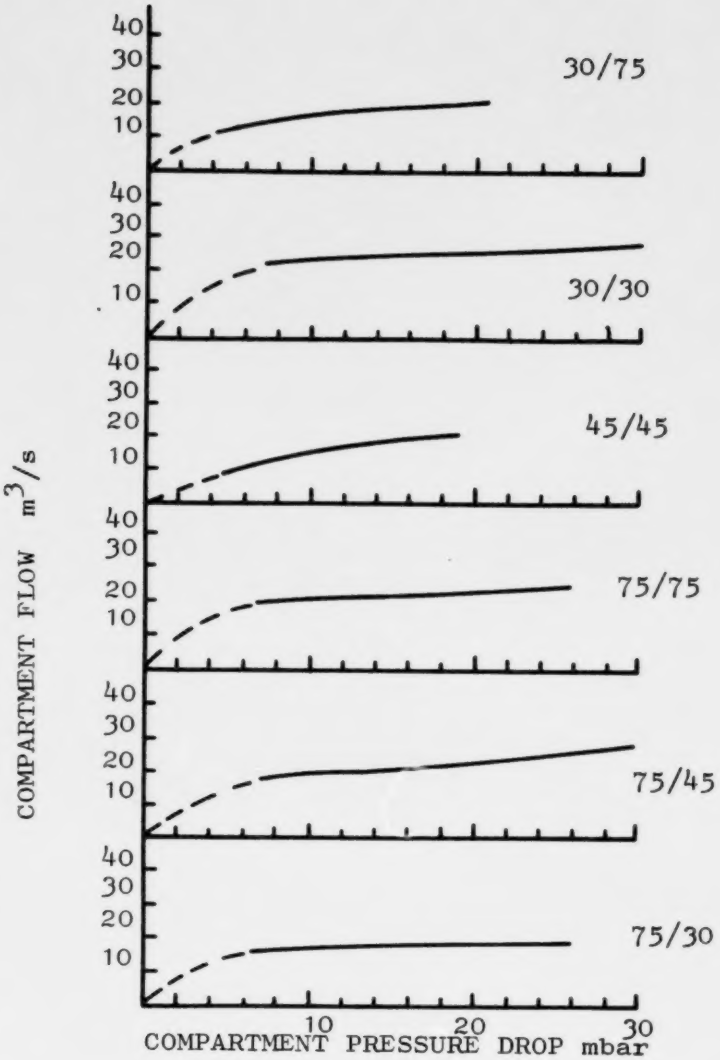


FIGURE 2.

AVERAGED COMPARTMENT FLOW - PRESSURE DROP RESULTS FOR FABRIC 4 (PTFE POLYESTER FELT LAMINATE) FOR TEST RUNS INVOLVING DIFFERENT SHAKE CLEANING CYCLES.

THE TWO NUMBERS AGAINST EACH PLOT GIVE THE INTERVAL BETWEEN SHAKING (min) AND THE DURATION OF SHAKING (secs).

resulting graphs obtained. Again, because of the influence of other compartments (whose condition was sometimes poor) there are generally few data relating to conditions of low pressure drop.

To further simplify comparisons of performance, the derived parameter specific flow (Q_s) was calculated and assessed. Specific flow is defined as:

$$Q_s = \frac{\text{Flowrate through compartment}}{\text{Pressure drop x fabric area}} \quad m^3/s \quad \text{bar } m^2$$

The mean values of Q_s calculated for the 4 fabrics under various cleaning conditions are given in Table 5. The higher the value of Q_s, the more advantageous is the combination of fabric and cleaning method. It can be seen that for shaking, improvements are brought about by an increased frequency and duration of shaking. With reverse air cleaning, the picture is perhaps similar, although less clear cut, with Fabric 4 behaving somewhat anomalously. The most effective means of maintaining a high specific flow is to clean the bags with a combination of shaking and reverse air.

Fabric 1 exhibited the highest Q_s values, and it is therefore unfortunate that the excessive dust quantities retained by this material caused such severe operating and maintenance problems. Fabric 2 performed least satisfactorily. Fabric 3 gave good values of Q_s during combined shaking/reverse air trials - slightly better than Fabric 4, which, as will be described later has other operating advantages.

At the Aldwarke baghouse, there has been a progressive re-bagging of compartments with Fabric 4 (Goretex) and it has been possible to follow trends in performance through a continuous monitoring exercise similar to that at Templeborough. The evidence indicates a gradual reduction in pressure drop as successive compartments were re-bagged. Additionally, data from Aldwarke have confirmed that if the normal operating cycle of the baghouse is interrupted and bags fail to be cleaned, then Fabric 4 will recover to its former state after a single cleaning cycle. This is considered to be due to the structure of the fabric, which results in surface filtration taking place. Other fabrics, which exhibit depth filtration and dust penetration require several cleaning cycles to restore the usual flow/pressure drop relationships. In practical terms, this is an important advantage of Fabric 4.

POWER CONSIDERATIONS

One of the motivations of this research was to identify combinations of filter medium and cleaning technique which would result in reduced power consumption. The waste gas

TABLE 5.

MEAN SPECIFIC FLOW (Q_s) COMPARISON

ALL CONDITIONS

CLEANING METHOD	FABRIC 1	FABRIC 2	FABRIC 3	FABRIC 4
SHAKING[a]	$m^3/s.bar.m^2$	$m^3/s.bar.m^2$	$m^3/s.bar.m^2$	$m^3/s.bar.m^2$
30/75	1.62	1.09	1.17	1.02
30/30	1.40	1.04	1.10	0.83
45/45	1.34	0.86	1.19	1.03
75/75	1.31	1.08	1.07	0.99
75/45	1.28	0.95	0.92	0.98
75/30	1.09	0.99	0.95	0.82
REVERSE AIR[b]				
30/60	1.29	0.84	1.07	1.02
30/30	1.19	-	-	-
30/20	-	0.88	1.18	1.28
75/60	-	0.84	0.84	0.93
75/20	1.05	0.91	0.86	1.09
150/60	-	0.88	0.87	-
COMBINED[c] Shaking/Reverse Air				
30/75/20	-	1.51	2.05	1.48
30/30/20	-	1.41	1.88	1.80
45/45/30	2.22	1.12	1.50	1.47
60/45/30	2.70	1.29	1.99	1.24
75/30/20	-	1.19	1.61	1.48

a The two figures listed refer to the interval between cleaning (min) and duration of shaking (s)

b The two figures listed refer to the interval between reverse air cleaning (min) and duration of reverse air (s)

c The three figures listed refer to the interval between cleaning (min), the duration of shaking (s) and the duration of reverse air (s).

power is readily computed from the waste gas flow and pressure drop data, but care needs to be taken in comparing power figures, since a medium which passes a greater volume for a given pressure drop would register a higher waste gas power figure. To overcome this problem, mean specific energy (E_c) figures have been calculated. These all relate to the same gas flowrate (20 m^3/s - a typical operating figure for the baghouse test compartment) and are therefore comparable (Table 6).

From these figures it is possible to derive power cost data, assuming a steady flow of 20 m^3/s. From the wide range of E_c found there will clearly be a wide range of power costs. For the real-life situation of varying flowrates and associated pressure drops, more complex calculations are needed, but the approach is the same. Cleaning the bags more often and for longer is generally advisable, with the exception of Fabric 4 where there was little variation unless combined shaking/reverse air cleaning was employed.

OTHER TEST RESULTS

During the course of the study, several other short duration tests and experiments were conducted and the more interesting results from these will be described here.

Tests were carried out on bags made of Fabric 1 turned inside out in an attempt to reduce the excessive weight of residual dust exhibited by this fabric. A significant improvement in retained dust weight was achieved, and satisfactory specific flow (Q_s) figures were obtained. However, some evidence was obtained of dust penetration through the material and also wear at the bottom retaining ring.

The manufacturers of Fabric 4 suggested that deflation of the bags alone would release the dust cake without operation of the shaker mechanism. Trials failed to bear this out, and simply resulted in a build up of the dust cake with a consequent increase in pressure drop across the compartments.

In an attempt to observe the extent to which dust particles penetrated the different filter media, the technique recently described by Felix and Smith (4) was used. This employs a low viscosity epoxy resin, which permeates and fixes the dust layer and filter medium. Once set, the sample can be sectioned and polished for microscopy. Figure 3 illustrates the results obtained for Fabrics 1, 2, 3 and 4 at a magnification of x60. The close weave of Fabric 2 with the dust layer well-packed on the surface contrasts with the much more open structure of Fabric 3, where there is clear evidence of penetration, which may in the long term lead to a deterioration in performance. Fabric 4 again shows a different behaviour, with the PTFE membrane

TABLE 6 MEAN SPECIFIC ENERGY (E_c) COMPARISON TO A BASE FLOW OF $20 m^3/s$

CLEANING[a] METHOD	FABRIC 1	FABRIC 2	FABRIC 3	FABRIC 4
SHAKING	kJ/m^3	kJ/m^3	kJ/m^3	kJ/m^3
30/75	0.89	1.34	1.24	1.43
30/30	1.04	1.39	1.32	1.75
45/45	1.08	1.70	1.22	1.42
75/75	1.10	1.35	1.36	1.46
75/45	1.14	1.52	1.58	1.48
75/30	1.34	1.46	1.53	1.76
REVERSE AIR				
30/60	1.12	1.74	1.36	1.42
30/30	1.22	-	-	-
30/20	-	1.67	1.24	1.14
75/60	-	1.74	1.73	1.56
75/20	1.37	1.60	1.69	1.34
150/60	-	1.66	1.68	-
COMBINED Shaking/Reverse Air				
30/75/20	-	0.96	0.71	0.99
30/30/20	-	1.03	0.77	0.81
45/45/30	0.66	1.30	0.97	0.99
60/45/30	0.57	1.12	0.73	1.17
75/30/20	-	1.22	0.91	0.98

---

[a] See footnotes to Table 5 for explanations of details of cleaning methods

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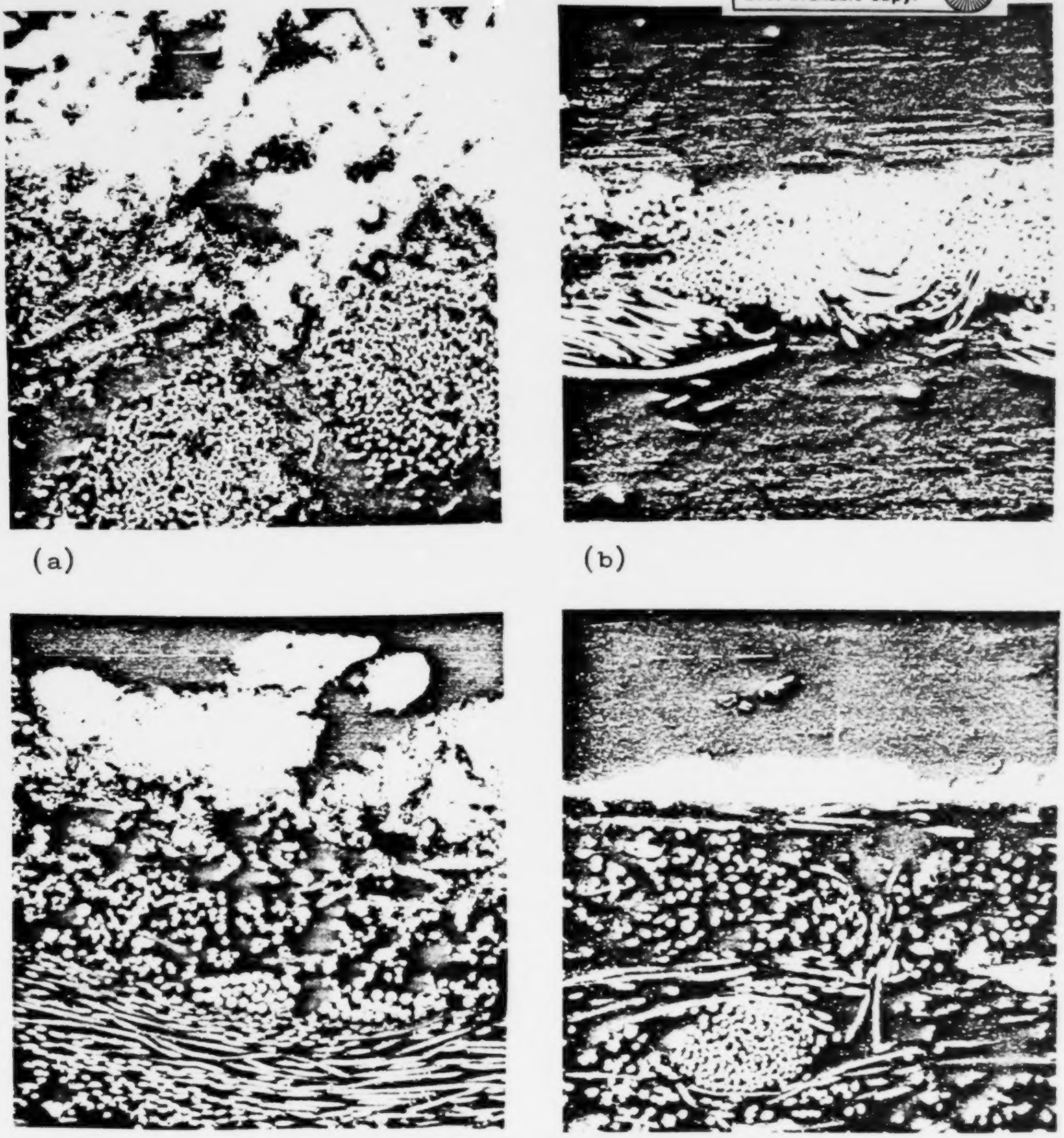

(a) (b)

(c) (d)

FIGURE 3. SECTIONS THROUGH DUST LAYERS COLLECTED ON FILTER MEDIA (x60)

FABRIC (a) Woven Heavy Duty Terylene
(b) Seamless Knitted Polyester
(c) Polyester Needlefelt
(d) PTFE Polyester Felt Laminate

preventing any dust penetration, despite the open structure of the supporting felt material.

OPERATION AND MAINTENANCE FACTORS

Although the details of baghouse routine operation and maintenance did not form a specific part of this study, it became apparent that unless attention is paid to these factors, then they could easily negate any of the benefits brought about by the careful selection of filtration medium and cleaning methods. Of particular importance are the regularity of cleaning, the correct seating of all dampers, the maintenance of the deflation air system and the condition of the shaker mechanism. Constant vigilance and prompt action in these areas are essential if efforts to improve baghouse performance and efficiency are to be successful.

CONCLUSIONS

Significant differences were observed between the performance of the four filter media tested. Fabric 1, a heavy duty woven terylene material, exhibited good flow-pressure drop relationships but suffered from excessive dust retention in its teased cleaning surface, which led to mechanical failures in the baghouse. Fabric 2, a lightweight knitted polyester material, performed the least well of all the fabrics tested and it is unlikely to be suited to electric arc furnace baghouses. Fabric 3, a polyester needlefelt material, gave good flow-pressure drop results but there are indications of dust penetration into the fabric which in the long term will lead to a deterioration in performance. Fabric 4, the PTFE membrane laminated to a polyester felt supporting material, had moderately good flow-pressure drop relationships, but also exhibited extremely good dust cake release and a rapid return to good performance after a period of poor baghouse operation.

For most fabrics, an increased frequency and duration of bag cleaning is beneficial in maintaining a low pressure drop and high waste gas flow. Fabric 4 appeared to be independent of these factors, but showed (in common with the other fabrics tested) a marked improvement when combined shaking/reverse air cleaning was employed.

A wide range of power consumption figures, and hence energy costs, is possible dependent on the type of filtration medium and cleaning method selected, and it is therefore relevant to pay attention to these aspects of baghouse design. However, experience at an operating baghouse demonstrates that unless there is careful maintenance of all mechanical parts then the additional running costs incurred can negate any benefits derived from fabric selection and cleaning methods adopted.

ACKNOWLEDGEMENTS

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OVERVIEW OF THE EPA PARTICULATE TECHNOLOGY R&D PROGRAM

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ABSTRACT

A number of key projects in the Environmental Protection Agency R&D Program having applicability to the steelmaking industry are presented. For ESPs there is presented the result of work on large diameter discharge electrodes which provide a decrease in penetration of up to a factor of 4 when compared to conventional small diameter electrodes. Also discussed is the multi-stage ESP which provides a collection efficiency that would require a collecting plate area 4 or 5 times larger with conventional ESP technology. The E-SOX technology makes use of the multi-stage concept to free up space in the ESP for SO_2 removals of up to 90%. Electrostatically augmented fabric filtration provides a reduction in pressure drop of about 50% as compared to conventional fabric filtration. Wind tunnel modeling of windbreaks for material storage piles indicate a potential for providing engineering design data that would allow significant emission reduction caused by wind erosion.

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OVERVIEW OF THE EPA PARTICULATE TECHNOLOGY R&D PROGRAM

INTRODUCTION

The Environmental Protection Agency particulate R&D program is concerned with the development of control technology for both ducted and fugitive sources of particulate matter. Additionally, work is underway on development of operation and maintenance procedures and the development of technology for reducing the emission of condensible aerosols. The work is distributed between the in-house experimental facility at Research Triangle Park, North Carolina, and various research organizations.

Historically, the program, in its ducted source work, was most heavily focused upon the control of emissions from the combustion of coal in utility and industrial boilers. However, because control technologies such as electrostatic precipitation and fabric filtration are generic by nature, they do have application to other industries such as steelmaking.

In this overview paper a number of the key generic technology projects in the particulate R&D program, that are concerned with electrostatic precipitation, fabric filtration, and fugitive emission control, are presented. They were picked for inclusion in this paper on the basis of their expected applicability to the steelmaking industry.

ELECTROSTATIC PRECIPITATORS

EPA's electrostatic precipitator (ESP) research has concentrated on improving performance and operation, especially with high resistivity dusts and back corona, decreasing size and cost, upgrading performance for operation with desulfurization systems, integrating sulfur dioxide control into the ESP, and developing performance and cost models.

Historically, with low resistivity dusts, ESPs have been designed for high corona currents. Even with these high corona currents the absence of a back corona problem allows development of high field strength. As a consequence, the ESPs operated well and the particles were easily charged and collected. High corona currents were achieved by use of small diameter discharge wires (approximately 0.3 cm) or use of electrodes with a multiplicity of discrete discharge points. Where the allowable useful current is limited by high resistivity, the low corona onset voltage and fairly steep voltage/current relationship results in a decreased electric field strength. The combination of low current density and electric field produced by conventional discharge electrodes requires that a high SCA be provided to meet emission standards.

Experimental studies at the EPA 840 actual m^3/min field pilot unit at TVA's Bull Run power plant and the in-house 28 actual m^3/min pilot ESP have shown that the use of larger diameter, smooth-surface electrodes (approximately 1 cm in diameter) can provide a significant improvement in ESP performance--

especially when high resistivity dust is collected. The large diameter electrodes allow operation at high field strengths and useful current densities. The operating current density, and thus the useful operating power, for the large diameter electrodes was found to be less than that for conventional size electrodes. For moderate (8×10^{10} ohm-cm) to high ($> 2 \times 10^{12}$ ohm-cm) resistivity dusts, the increase in the electric field more than compensates for the reduction in useful power. As can be seen from Table 1, the large diameter wires reduce the penetration for high resistivity dust by a factor of 4 and the penetration for moderate resistivity dust by a factor of 1.25. Economic analysis has shown that the large diameter wire technology is applicable in both new and retrofit situations when the dust resistivity is greater than about 8×10^{10} ohm-cm. The application of this technology is being further pursued.

In conventional ESPs particle charging and collection take place in the same electrical section. It has been found that, for the higher resistivity dusts, separation and optimization of the charging and collection steps can lead to significant improvements in performance.

A number of precharger techniques have been worked upon including the trielectrode (1), cold-pipe (2), and charged droplet. One of the most promising is the cold-pipe precharger shown in Figure 1. It consists of discharge wires interspersed with grounded pipes through which cooling water flows. The purpose of the cooling water is not to cool the gas stream but to cool the dust layer that forms on the pipes. Cooling the dust layer decreases the resistivity, thereby allowing high field strength and current which puts high charge levels on the particles. The direction of gas flow for the front view of the cold-pipe, which is on the left side of the figure, is perpendicular into the paper; for the side view the gas flow is from left to right.

Combining the cold-pipe precharger with wire-plate collectors using large diameter wires provides an even further improvement in performance. Large diameter wires in the collector sections allow development of high field strengths and also provide sufficient corona current to clamp the dust layer to the plates, thereby minimizing non-rapping reentrainment. Figure 2 shows the multi-stage ESP which consists of collector sections each of which is preceded by a cold-pipe precharger. With high resistivity particulate matter a multi-stage ESP will give the same collection efficiency as a conventional ESP operating with relatively low currents and fields and having 4 or 5 times the collecting plate area. Operation of the multi-stage ESP with the cold-pipe precharger and large diameter wires in the collector sections has been done on the EPA in-house 28 actual m^3/min ESP. Further work on this concept is scheduled on the EPA 425 actual m^3/min ESP at Colorado Public Service's Valmont power station.

Multi-staging, when retrofitted to an ESP that is working well and is in compliance with the particulate matter regulations, will have more capacity than is actually needed. This suggests that some portion of the ESP internals can be removed. This freed up space, fitted with suitable nozzles, can be used for removal of sulfur dioxide from a flue gas by injecting droplets of an alkaline reagent.

This system, which has been named E-SOX, for the removal of sulfur dioxide along with the particulate matter in an ESP, is shown schematically in Figure 3. The ESP has had some internals at the inlet removed; cold-pipe prechargers and large diameter wires are installed in the remainder of the ESP. The alkali reagent shown being used here is a high calcium lime that has been slaked and slurried by techniques that have been developed for conventional spray drying flue gas desulfurization.

The E-SOX system has been evaluated on the in-house 28 actual m^3/min ESP using two fluid nozzles for the alkali reagent injections. The sulfur dioxide removal results are shown in Figure 4. Two reagents were used, sodium carbonate solution and lime slurry. With the sodium carbonate inlet concentrations of 15 and 30% by weight and at flow rates ranging from 26 to 75 liters per hour, the sulfur dioxide removal ranged, for an inlet concentration of 1200 to 1500 ppm, from about 50% to almost 90%, within 2 seconds of residence time. With a slurried lime injection, whose concentration was 7 and 15% by weight, the sulfur dioxide removal in the same 2 seconds of residence time ranged from about 40% to almost 60%. Maximum sulfur dioxide was removed at the higher injection rates. The removal was not found to be highly sensitive to reagent concentration. For the lime experiments the maximum stoichiometry of calcium to sulfur was about 1.8 based upon inlet sulfur dioxide. In both cases the injected droplets were completely dried in considerably less than 2 seconds, and the deposits on the ESP could be rapped off. In this series of experiments no attempt was made to optimize the sulfur dioxide removal. In a typical ESP retrofit, enough of the internals should be removable to obtain 2 seconds of residence time. The remainder of the ESP can be multi-staged not only to regain original particulate collection performance but also to capture the injected reagent.

The costs for E-SOX have not been fully worked out. However, it is expected that the process should be among the lowest cost of the various flue gas desulfurization techniques. The use of an existing ESP makes it unnecessary to add equipment, such as a spray drying chamber, for sulfur dioxide capture; the lime system is the same as is required for some of the other processes. One advantage of E-SOX is that the injection of a large quantity of droplets lowers the gas temperature and volume which causes a reduction in particle resistivity and an increase in SCA. The E-SOX project is expected to be moved onto a larger pilot unit using actual flue gas as the next stage in its development.

E-SOX, if successfully developed, would be a low-cost retrofit for reducing emissions of sulfur dioxide from coal-fired power plants. This is significant for several reasons: (1) coal-fired power plants with ESP particulate control technology represent the largest source category for sulfur dioxide emissions in the U.S., and (2) the high cost of controlling sulfur dioxide with existing technology is a major issue to be considered in air pollution policy analysis. It would be especially useful for those situations in which there is not room for a spray drying chamber.

FABRIC FILTRATION

Historically, fabric filtration has been used for a considerable time in industry. More recently with increasing use of low sulfur coals, with their high resistivity fly ashes, it is being applied more frequently to utility and industrial boiler particulate matter control.

In the EPA particulate program it has been concluded that, of all the parameters involved in fabric filtration design, electrostatics, when properly applied, is the dominant.

Electrostatically augmented fabric filtration (ESFF) is a technique in which an electrostatic field is established across the fabric to cause preferential deposition of the particulate matter on some areas while leaving other areas open to gas flow. This open area causes a lowered pressure drop for the baghouse. Much of the work to date has been with the electric field parallel to the surface of the fabric. Typically the field was generated between electrodes, at the surface of the fabric, running the length of the bag, and placed about 2 cm apart. The electric field strength is from about 2 to 8 kV/cm. In pulse-jet operation the wire support cage is adapted for developing the electric field as shown in Figure 5 (3). Adjacent wires are insulated from each other thereby allowing the cage itself to be electrified. For reverse-air, which does not use a cage, stainless steel yarns have been woven into the fabric warp as shown in Figure 6. The fabric is fiberglass with a Teflon finish; the yarn is 316 stainless steel having 90 fibers each 22 μm in diameter (4). The alternate yarns have the electric field developed between them, the same as in pulse-jet.

The ESFF effect has been shown for fly ashes on the small in-house baghouses. It has been shown for both reverse-air and pulse-jet with the EPA 28 actual m^3/min pilot unit having 2.4 m bags on an industrial boiler at the DuPont Waynesboro facilities. It has been operating for about 14 months, using reverse-air, at the EPA 140 actual m^3/min pilot unit at the Southwest Public Service Harrington power station in Amarillo. At the Harrington power plant the bags were full utility size, each being 9.2 m long and 0.3 m in diameter as shown in Figure 6.

Typically, for fly ash the pressure drop across an ESFF baghouse is about 50% of the pressure drop across a conventional baghouse (3,5). This means that one can minimize the pressure drop and consequently the fan power or else decrease the number of bags and consequently the capital cost.

A series of experiments were performed in-house on both reverse-air and pulse-jet using redispersed particulate matter from a spray drying process used in sulfur dioxide capture. In spray drying a lime slurry is injected into a chamber to react with the sulfur dioxide. The resulting mixture consists of fly ash, and reacted and unreacted lime. For spray drying by-product particulate matter, the pressure drop was reduced by about a factor of 6 as compared to conventional filtration. Figure 7 is a pressure vs time trace which shows dramatically the effects of turning the field on. At the start, with the power off, the pressure drop was continuing to rise and would have eventually gone off the chart if continued. The pressure drop started to respond immediately to turning on the field.

The ESFF effect that has been discussed up to now has been based upon the action of an electric field upon particulate matter containing only natural charge. No corona for charging the particles was generated. The measured natural charge on fly ash was about 0.1 to 0.2 μC/g, for spray drying by-product the charge-to-mass was 1 to 2 μC/g. The difference in the pressure drop reduction for fly ash as compared to spray drying material shows the effect of this difference. Varying the electric field has also been seen to affect the pressure drop reduction.

Work is underway on techniques in ESFF for simultaneously increasing the field strength and increasing the charge on the particles. There is good indication that by doing this it would be possible to achieve pressure drop reduction for most particulate matter that will equal that which was achieved with spray drying material.

FUGITIVE EMISSIONS

Several projects are underway on investigating control technology for fugitive emissions. One project that may have significance for industries, such as steelmaking, is the development of engineering design data for control of wind blown particulate matter from storage piles by use of windbreaks.

Windbreaks for the control of wind blown particulates are not new. However, very little engineering data are available on how to engineer them. To develop this data, wind tunnel experiments have been conducted to determine the optimal windbreak porosity, size, and location for storage pile fugitive dust control (6). The low speed, open return EPA Meteorological Wind Tunnel has a test section 2.1 m high by 3.7 m wide by 18.3 m long. In the wind tunnel a neutrally stratified, rural atmospheric boundary layer was simulated.

In the first set of experiments a non-erodible material was used to represent a conical storage pile as shown in Figure 8. Straight sections of windbreak material of various combinations of porosity, height, length, and location were placed upwind of the pile. The windbreak height and length are given in terms of pile height and base diameter, respectively, and the position is the distance between the windbreak and pile base given in terms of pile height. There were 24 combinations of the parameters.

The surface wind velocity profiles were mapped using calibrated thermistors for the model pile without windbreaks in place. In Figure 9 a top view is shown with contours of normalized wind speed, U/U_{10}, where U is the wind speed measured at the pile surface and U_{10} is the wind speed at the equivalent full-scale height of 10 m in the absence of the pile. The wind velocity is highest on the upstream face near the crest extending down both sides.

Typical velocity reduction percentages are shown in Figure 10. Velocity reductions of about 75% are indicated for the previously identified high velocity areas of the cone. Significant velocity reductions are also indicated for other portions of the cone. Similar work is being completed for oval storage piles.

It is assumed that a reduction in surface wind velocity will result in a decrease in fugitive wind blown emissions from the storage pile. Future work is being planned to verify these results on full-scale storage piles. If the verification is successful, a useful engineering design tool would be available to the steelmaking and other industries.

OTHER ACTIVITIES

In addition to the work described in previous sections, EPA has a strong program in modeling and fundamentals. The purpose of the modeling/fundamentals program is to provide design and performance models for the particulate control devices, which are based on a sound understanding of the underlying physics of the particulate collection process. The ESP work has resulted in a computer model that is in widespread use by vendors, users, and researchers (7). Work is underway to improve the ESP model in the areas of effects of electrode geometry, electrical conditions, and space charge. The program has produced a useful model for fabric filters. The current version of the model does not include electrostatic effects. However, work is underway to introduce the effects of application of electrostatics into the fabric filtration models. A major effort is underway to extend the usefulness of these models to the control of particulate matter from the varied industrial sources such as steelmaking.

There is additional work being done in fugitive particle control involving the development of engineering design information for hoods used for collection of particles and fume. Operation and maintenance manuals are being developed for ESPs and baghouses. Finally, research is being done to develop technology to decrease the emissions of condensible aerosols.

CONCLUSION

This paper has presented an overview of the key projects of the EPA particulate technology R&D program, which may be of interest to the steelmaking industry. Work will be continuing in the areas that include ESPs, electrostatically augmented fabric filtration, and control of fugitive emissions. Discussion of specific problems, in particulate matter control in the steelmaking industry that may make use of these technology areas, would be welcomed.

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Table 1. COMPARISON OF LARGE AND SMALL DIAMETER DISCHARGE ELECTRODES

Resistivity ohm-cm	8×10^{10}	2×10^{12}
Electric field ratio (E_L/E_S)	1.60	1.19
Current density ratio (j_L/j_S)	0.41	0.69
Power ratio (P_L/P_S)	0.55	0.81
Overall migration velocity ratio (w_L/w_S)	1.12	1.33
Penetration ratio (Pt_L/Pt_S)	0.80	0.25

NOTE: Subscript L refers to large diameter electrode and subscript S refers to small diameter electrode.

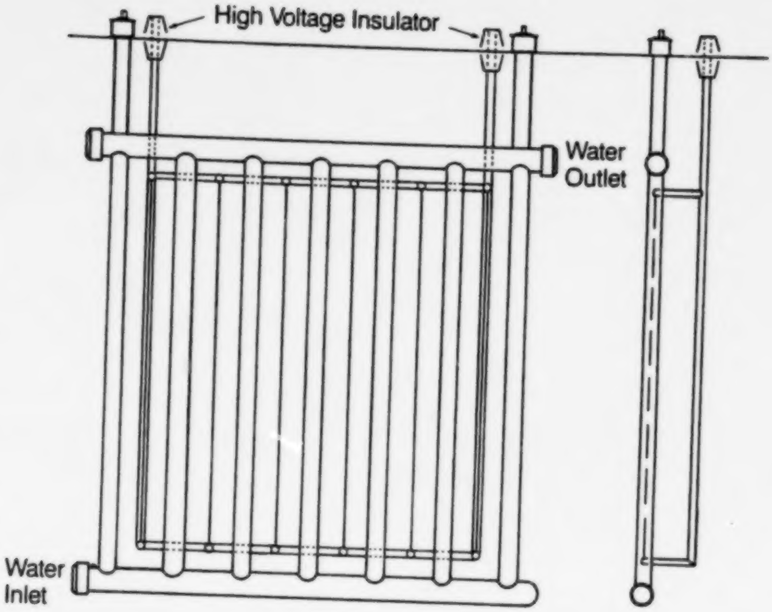

High Voltage Insulator
Water Outlet
Water Inlet

Figure 1. Cold-Pipe Precharger

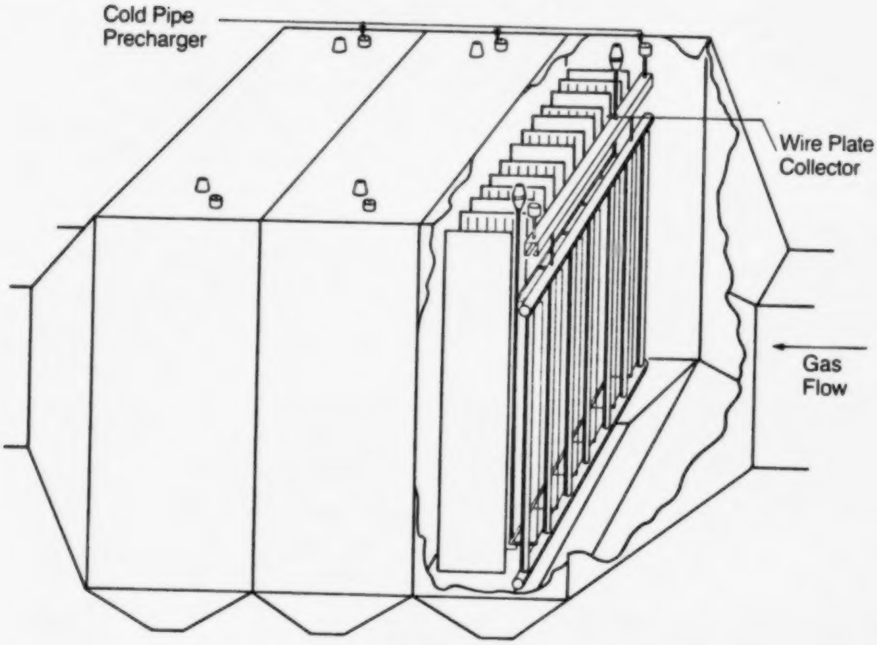

Cold Pipe Precharger
Wire Plate Collector
Gas Flow

Figure 2. Multi-Stage Electrostatic Precipitator

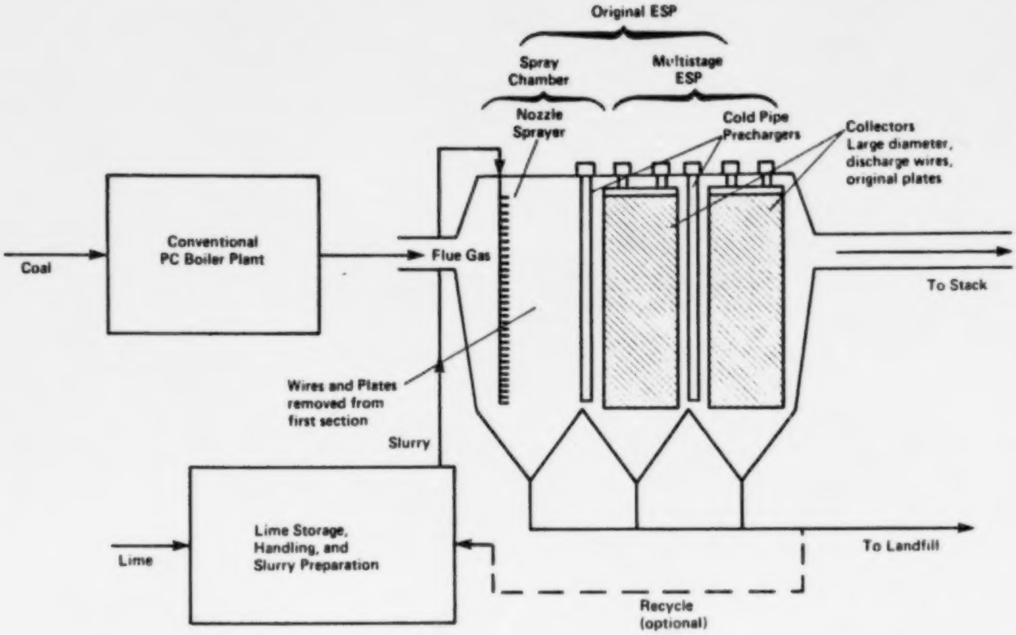

Original ESP
Spray Chamber
Multistage ESP
Nozzle Sprayer
Cold Pipe Prechargers
Collectors Large diameter, discharge wires, original plates
Coal
Conventional PC Boiler Plant
Flue Gas
To Stack
Wires and Plates removed from first section
Slurry
Lime
Lime Storage, Handling, and Slurry Preparation
To Landfill
Recycle (optional)

Figure 3. Schematic of E-SOX Process

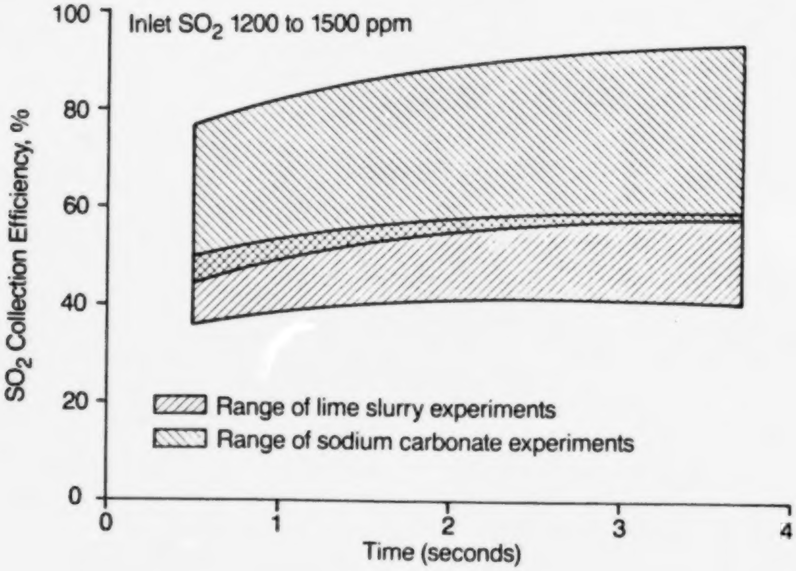


Figure 4. E-SOX Data for Sodium Carbonate and Lime Slurry Experiments

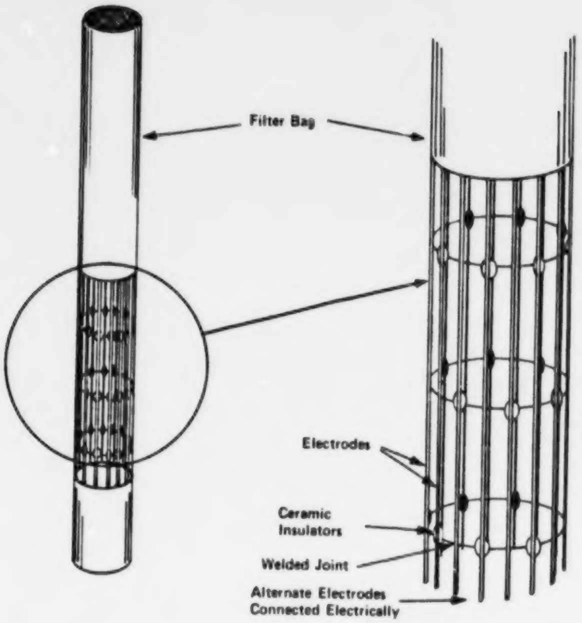

Filter Bag
Electrodes
Ceramic Insulators
Welded Joint
Alternate Electrodes Connected Electrically

Figure 5. Pulse-Jet ESFF Electrode/Bag Assembly

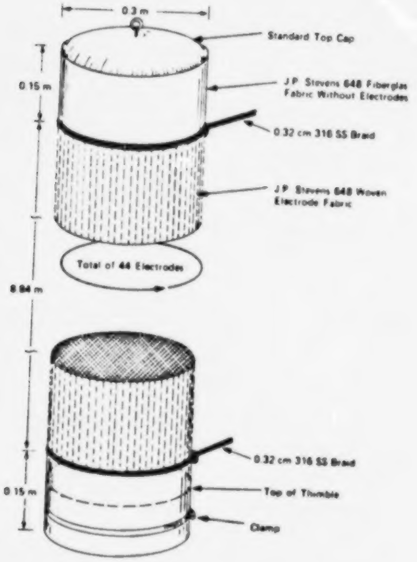

0.3 m
Standard Top Cap
0.15 m
J.P. Stevens 648 Fiberglas Fabric Without Electrodes
0.32 cm 316 SS Braid
J.P. Stevens 648 Woven Electrode Fabric
Total of 44 Electrodes
8.84 m
0.32 cm 316 SS Braid
0.15 m
Top of Thimble
Clamp

Figure 6. Reverse-Air Woven-in Electrode ESFF Bags

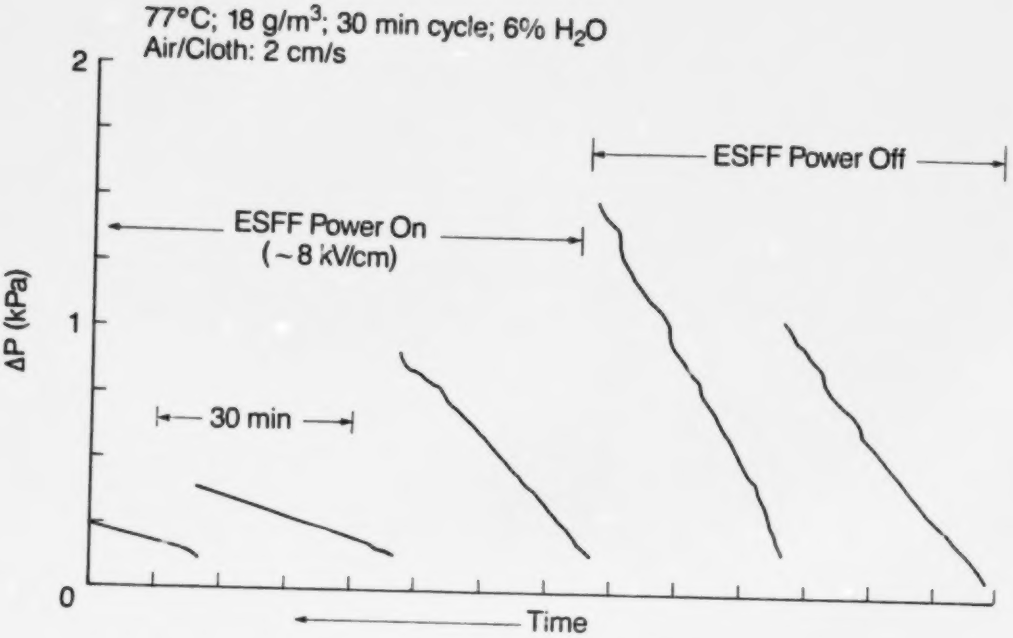
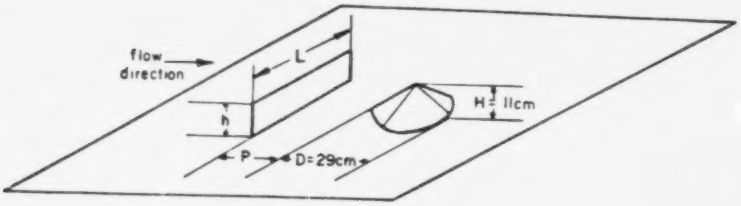
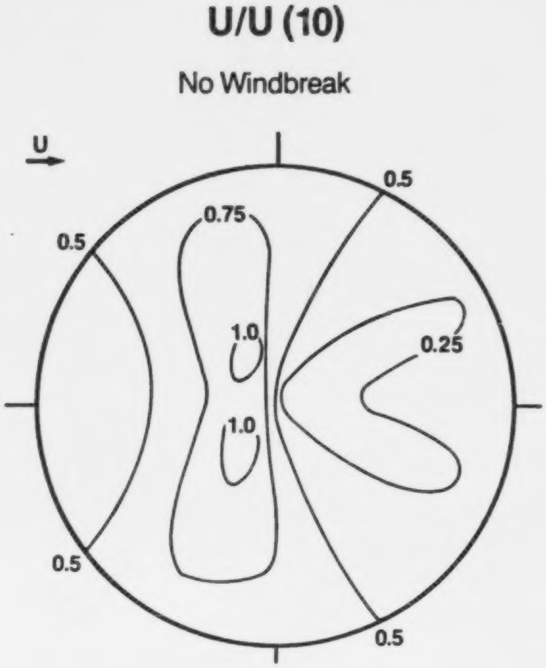


Figure 7. Effect of Turning ESFF Field On


flow direction
L
h
P
D=29cm
H= 11cm

Windbreak Specifications	
Porosity	50%, 65%
h	0.5H, 1.0H, 1.5H
L	1.0D, 1.5D
P	1H, 3H

Figure 8. Conical Storage Pile and Windbreak Placement and Specifications

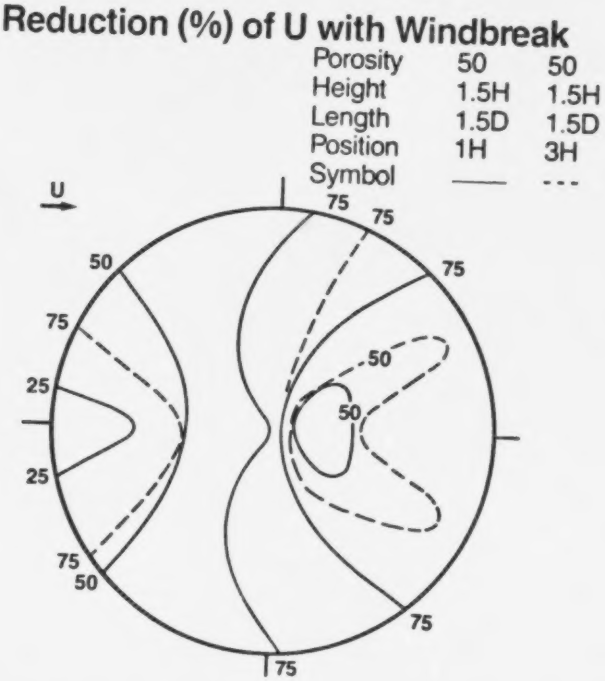


U/U (10)

No Windbreak

U
0.5
0.75
0.5
1.0
0.25
1.0
0.5
0.5

Figure 9. Surface Wind Velocity Profile for Conical Storage Pile Model Without Windbreak



Reduction (%) of U with Windbreak

Porosity 50 50
Height 1.5H 1.5H
Length 1.5D 1.5D
Position 1H 3H
Symbol —— - - -
U
75
75
50
75
75
50
25
50
25
75
50
75
75

Figure 10. Profile of Velocity Reduction Percent for Conical Storage Pile Model with Windbreak

APPLICATION OF THE EPA/SoRI ESP MODEL TO IRON AND STEEL INDUSTRY

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APPLICATION OF THE EPA/SoRI MODEL TO IRON AND STEEL INDUSTRY

I. Introduction

For the past 10 years, EPA has been working with Southern Research Institute and Research Triangle Institute to develop a computer simulation of the electrostatic precipitation process. The model developed as part of this research has proven to be a useful tool and has been used extensively in the electric utility industry. The model has been successfully used to guide the design of ESPs installed on coal-fired boilers for the past several years.

The model has also been used as a troubleshooting tool for many utilities. Proper use of the model makes it possible to determine probable causes of poor performance and to determine the effectiveness of proposed correctable action.

Although the bulk of the data used to verify the model has come from coal-fired utility boilers, the model can be applied to ESPs on other sources. The purpose of this paper is to present the basics of the model, to discuss the data necessary to use the model, and to discuss how the model can be applied to the iron and steel industry. In addition, we will also discuss some of the advanced work now underway to make the model more useful.

II. Overview of the Model

The ESP model predicts precipitator performance by first performing the collection efficiency calculations under ideal conditions. The ideal results are then corrected for non-ideal conditions such as rapping reentrainment and sneakage. In the model the precipitator is divided into sections with independent electrical conditions. Each electrical section is further divided into incremental lengths on the order of the wire-to-wire spacing in the ESP. The particle collection efficiency of each increment is calculated and the overall efficiency is calculated from the incremental efficiencies. The effects of particle size distribution are accounted for by dividing the inlet dust into particle diameter bands. Each particle diameter band is treated separately in the model efficiency calculations.

The ESP model uses the Deutsch equation to calculate the collection efficiency of each particle sized band in each incremental length. The efficiency of particles of diameter d in one incremental length is given by:

$$E(d) = 1 - \exp\left[-w(d)A/Q\right] \qquad (1)$$

where E(d) = efficiency of particles of diameter d, A is the area of the collector plate, Q is the gas flow rate, and w(d) is the electrical migration velocity of particles of diameter

$$w(d) = qE_pC/(12\,\pi d_\mu) \qquad (2)$$

where q is the charge on the particles, E_p is the electric field at the plate, μ is the gas viscosity, and C is the Cunningham correction factor.

The overall mass efficiency, E_o, is determined by integrating the individual particle efficiency over the particle size distribution, f(d),

$$E_o = 1 - {}_o\int^{\infty} f(d) \text{ Exp} - [w(d)Q/Q]dd \qquad (3)$$

The calculation of collection efficiency requires that the charge and electric field be calculated for each length increment. This calculation can be done by estimation formulas or rigorously by using equations developed by Smith and McDonald (1,2). The model provides the user with the option of using the estimation formulas or the rigorous calculations.

After the ideal collection efficiency for the entire ESP is calculated, the model corrects the results for non-ideal factors. The non-ideal corrections account for sneakage (gas by-passage of the electrified region), non-uniform gas flow distribution, and rapping reentrainment. Sneakage and non-uniform gas flow are corrected for by reducing the calculated ideal efficiency. Rapping reentrainment is corrected for by adding an empirical rapping emission to the calculated emission. The amount of material to be included in the rapping emission and the particle size distribution of the rapping emission are based on empirical data for coal-fired boilers.

The results from the model are displayed in the form of overall mass collection efficiency and efficiency as a function of particle diameter. The model also provides the option of calculating the plume opacity for the particulate emission.

III. Input Data Requirements

The input data required for the model are shown in Table I. The input data can be divided into several categories:

1. ESP design and operation data
2. Flue gas data
3. Particle data
4. Non-ideal factor data

All the data, except for the last two, should be readily available either in ESP design manuals or ESP operating logs. The major difficulty is in determining appropriate values for the last two data items.

Detailed analysis of ESP data and model results for a number of industrial ESPs suggest that the appropriate values for the non-ideal correction factors for an ESP in good condition are in Table II.

The dust properties of electrical resistivity and particle size distribution are the most difficult of the input data to estimate. When an existing ESP is being studied, the dust properties can be determined by field measurements. However, in cases where a new ESP is being designed, the dust properties must be estimated.

Table I. INPUT DATA REQUIRED FOR ESP MODEL

A. ESP Design and Operating Data

- Number of electrical sections
- Length of each section
- Plate area of each section
- Number of wires in each section
- Wire-to-wire and plate-to-plate spacing
- Applied secondary voltage and current for each section

B. Gas Data

- Gas volumetric flow in each section
- Gas velocity in each section
- Gas temperature in each section
- Ion mobility

C. Particle Data

- Inlet mass loading
- Electrical resistivity of dust
- Dielectric constant of dust
- Particle size distribution
- Particle density

D. Non-Ideal Factors

- Gas sneakage fraction
- Standard deviation of the gas flow distribution
- Re-entrainment factors

Table II. SUGGESTED VALUES OF NON-IDEAL FACTORS FOR ESP MODEL

Sneakage fraction 0.1 for good practice
0.5 for best practice

Standard deviation of gas flow 0.25

Rapping factors as selected by model defaults

IV. Accuracy of the Model

The final test of any model is how well does it predict? The most extensive analysis of the model's ability to predict was reported by DuBard and Altman (3). They reported on the results of tests of the ESP model on several ESPs used to control fly ash from coal combustion. The data available for each of the ESPs modeled included complete particle size distribution data and electrical operating data. DuBard and Altman concluded that the model was at least as accurate as the measurements used to verify it. Thus, at least for the case of fly ash from coal combustion, we can say that the ESP model is an excellent predictor of ESP performance.

Another test of the model is how well it predicts trends and the effects of design and operating changes. The ability of the model to predict effects of changes in operating conditions is of special importance when the model is used for troubleshooting. In this situation the model does extremely well--even in cases where the available data are less than perfect.

V. Applications of the Model

The model can be used to evaluate bids and thus ensure that the ESPs proposed by vendors can meet the performance requirements. Perhaps the biggest problem with this use of the model in the iron and steel industry is the lack of data on important particulate properties and the wide variability of such properties from source to source. Thus considerable engineering judgement is required when the model is used to evaluate bids. Because of the uncertainty in the data for iron and steel sources, the model should be used to identify weaknesses in various bids. For example, the model is an excellent tool for studying the self-consistency of the engineering assumptions involved in ESP design. Also, the limited data combined with the model can be used to determine the bounds of reasonable design.

Troubleshooting is one of the most powerful applications of the ESP model. The model can help diagnose the causes of poor ESP performance and can also help estimate the performance improvement resulting from various corrective actions. The model can be used for troubleshooting even where the available data are incomplete. In fact, the model can be used to determine whether or not one should spend the money necessary to get complete data.

The troubleshooting procedure discussed below is described in more detail by McDonald (4). Although McDonald's report is specific to fly ash ESPs, the troubleshooting procedure can be applied to any ESP.

The first step in the troubleshooting procedure is to calculate the ideal collection efficiency of the ESP under perfect conditions. If the measured value of efficiency equals the ideal efficiency, the ESP can be assumed to be working well. An increase in performance is unlikely unless the proposed fix will significantly improve the electrical conditions.

The next step is to determine the efficiency under best practice conditions of sneakage and gas flow distribution (S = 0.05 and σ = 0.20). This calculated efficiency establishes the maximum reasonable efficiency possible from the ESP. If the measured value equals or exceeds this value, the ESP is working well.

The third step is to determine the efficiency for good practice conditions of sneakage and gas flow distribution (S = 0.1 and σ = 0.25). If the measured value of efficiency equals the calculated value, the ESP can be considered to be in good condition. The difference in the best practice and good practice performance is a good predictor of the improvement likely if the ESP were modified to achieve the best practice condition.

If the measured efficiency is significantly less than the good practice predicted efficiency, there are three possible explanations:

1. The data used in the model are in error.
2. The operating currents in the ESP are not completely useful.
3. Factors such as rapping, sneakage, and gas flow distribution are significantly worse than expected if good practice were followed.

If the data are suspect, the model should be run with a range of values for the suspect data. This set of runs will establish bounds for likely performance of the ESP and will determine the sensitivity of the model predictions to the input data. If necessary, a field measurement program can be undertaken to obtain the data to which the model is most sensitive.

After the model runs discussed above are made, the ESP electrical conditions should be examined in order to determine if the operating currents in the ESP are completely useful in the precipitation process. If excessive sparking or back corona is occurring in the ESP, the measured currents will not be totally useful in the precipitation process.

If the poor ESP performance cannot be traced to electrical operating conditions, the non-ideal effects of non-uniform gas flow distribution, gas sneakage, and reentrainment should be examined in a systemmatic manner. The non-ideal effects identified by the modeling as significant should then be studied experimentally. If the experiments show that the model values are correct, then steps should be taken to correct the non-ideal factor.

The troubleshooting procedure outlined above can be a valuable tool in helping diagnose the causes of poor ESP performance. Since the procedure involves only limited experimental data, it is cost effective. Use of the procedure can result in time and cost savings by giving direction and helping to focus the field experiments on those factors that actually need to be measured.

VI. Future Direction

Work is underway to translate the computer code to allow use of the model on a wide range of computers. The version documented in Reference (1) runs on most mainframe computers and on many minicomputers. A version is also available for the Tandy Radio Shack Models I, III, and IV (5). Versions for the IBM-PC and the Tandy Model 2000 will be available in early 1985.

Work is also underway to allow the model to handle conditions not presently handled by the model. For example, the model does an excellent job of predicting ESP performance for wire duct ESPs with round wires and known electrical conditions. However, the model does not predict the electrical operating conditions. Nor does the model allow for discharge electrodes that are not round wires. (Other electrode shapes must be simulated by an appropriate round wire.) Research is presently underway to allow the model to deal with various discharge electrodes, such as the rigid electrodes now being developed. This research will also allow the model to handle variable discharge electrode geometries and discharge-electrode-to-discharge-electrode spacing in the same electrical section. An initial version of this electrical model for the Tandy Model 2000 and the IBM-PC microcomputers is planned for early spring 1985.

Work has also begun to acquire data necessary to apply the model to non-utility sources of particulate matter. Most of this work is being done in-house. We plan to characterize the particulate matter from a broad range of sources as to particle size distribution and electrical resistivity. We also plan to obtain as much data as possible from operating ESPs to help verify the model.

VII. Conclusion

Although the model has not been well verified for the iron and steel industry, it can be an extremely useful tool for troubleshooting existing ESPs and for evaluating bids for new ESPs. The model, especially when used with good engineering judgement, can give accurate and reliable answers. But as with all computer programs, the expression "garbage in/garbage out" applies. The answer provided by the model is only as good as the data entered into the model.

VIII. References

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SESSION 3

SOLID WASTE/MULTIMEDIA POLLUTION ABATEMENT

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DEWATERING OF BLAST-FURNACE AND BASIC-OXYGEN-PROCESS SLUDGES BY BELT-PRESS FILTRATION--FIELD TRIALS

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ABSTRACT

Wet sludges produced in wastewater-treatment systems of blast-furnace and basic-oxygen-process (BOP) operations must be effectively dewatered for ease and economy of reuse or disposal. Most existing systems utilize conventional vacuum filters which have limitations with respect to formation, release, and/or solids content of the dewatered product. In the investigation of dewatering alternatives, U. S. Steel Corporation and Nalco Chemical Company have studied the application of twin-belt-press filtration. After obtaining encouraging results in laboratory tests and on a pilot-sized unit, full-scale field trials were conducted.

A commercially available one-half-metre belt press was used in one-week, on-site trials for dewatering sludge from ironmaking (blast furnace) and steelmaking (BOP) operations. After each feed was characterized, optimum belt-press operating parameters were established. Polymer requirements ranged from about 1.6 pounds per ton (lb/ton) of dry solids for the blast-furnace sludge to about 2.6 lb/ton for the BOP sludge. Other variables studied were feed rate, belt tension, belt speed, and roll configuration. During demonstration trials, rigid filter cakes were consistently produced having typical cake solids contents of 69 percent for the blast furnace and 71 percent for the BOP sludge. Production rates for the dewatered cake and other operating criteria are discussed.

The study has demonstrated that belt-press filtration is capable of dewatering sludges from blast-furnace and BOP operations and has established the process parameters required for successful operation.

BACKGROUND AND INTRODUCTION

Sludge dewatering has become an increasingly critical problem in the American steel industry with an estimated 3-million metric tons of waste sludges generated annually (1)*. Wet sludges produced in wastewater-treatment systems of blast-furnace and basic-oxygen-process (BOP) operations account for over half of this total and must be effectively dewatered for ease and economy of reuse or disposal. These sludges are comprised mostly of fine iron oxide, dolomite, and dust particles dispersed in water. Most existing dewatering systems utilize conventional vacuum filters which have limitations with respect to formation, release, and/or solids content of the dewatered product. Because of these limitations, there is a critical need to improve the dewatering of these sludges to produce the driest cake at the most economical cost.

One type of equipment that is not currently used for dewatering blast-furnace and BOP sludges, but has shown excellent performance in other applications, is the belt-press filter (2). A simplified sketch of this type of equipment is shown in Figure 1. In this type of filter, sludge is squeezed between two filter belts by sets of rollers that exert increasing pressure as the sludge passes through the unit, providing a well-dewatered cake (3). Belt-press-filtration technology has been successfully applied to the dewatering of municipal sanitary sludges, various oily wastes (refineries, tanneries), and very abrasive wastes (coal-preparation plants) (4). No reference could be found, however, to belt-press filtration of sludges from iron and steelmaking (blast furnace and BOP).

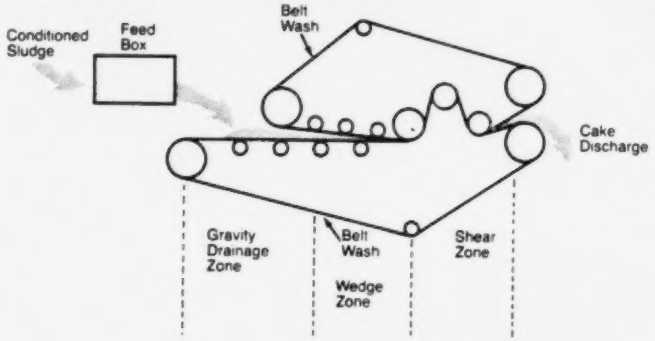

Figure 1. Schematic of a Belt Press Filter.

Nalco Chemical Company and U. S. Steel Corporation (USS) have conducted a joint laboratory study to investigate belt-press filtration of these types of sludges. Early laboratory-scale results using modified Buchner Funnel tests (5) and a small-scale static press (6) indicated potential for the application of belt-press filtration to steel-mill sludges. Further testing (7) on a pilot-sized scale model belt press confirmed the feasibility for this type of equipment to dewater blast-furnace and BOP sludges. What was still required, however, were field trials at blast-furnace and BOP locations with a commercially available belt press to conclusively verify the laboratory and pilot-scale studies on a larger scale. If successful, such a trial would establish the polymer type and dosage rate required as well as operating parameters such as feed rate, belt tension, belt speed, and roll configuration and also a measure of solid content and production rate of the dewatered cake.

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*See References.

MATERIALS AND METHODS

A commercially available one-half-metre belt press was used for dewatering sludge from ironmaking (blast furnace) and steelmaking (BOP) operations in one-week trials at each site. The belt press was the same for each of the trials, an Arus Andritz-Ruthner Model SDM-20, shown in Figure 2

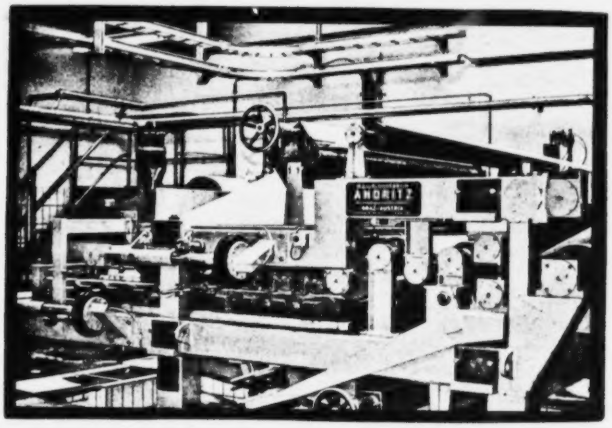

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Figure 2. Arus Andritz-Ruthner Model SDM-20
Twin-Belt Press

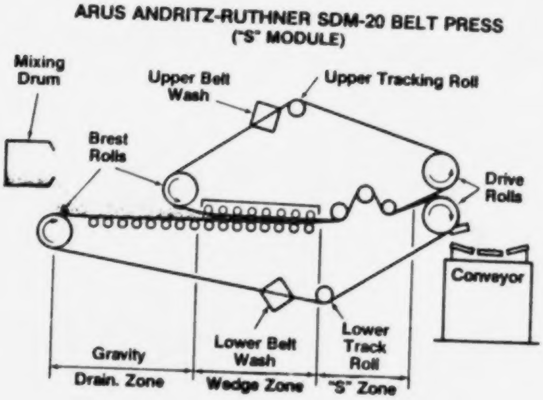
ARUS ANDRITZ-RUTHNER SDM-20 BELT PRESS
("S" MODULE)
Mixing Drum
Upper Belt Wash
Upper Tracking Roll
Brest Rolls
Drive Rolls
Conveyor
Lower Belt Wash
Lower Track Roll
Gravity Drain. Zone
Wedge Zone
"S" Zone

Figure 3

and depicted schematically in Figure 3. The SDM-20 press has an effective belt width of one-half metre and was chosen for these trials because of the ease of roll adjustment to vary roll configurations, i.e., the effects of several different types of machines could be tested with the single unit by modifying the roll configurations. Roll configuration variations were made in the "S" module as depicted in Figure 4. The code used to designate a roll configuration is identified as follows:

Numeral, first (3)	Number of rolls
Letter, second (S)	Type of curve
Third designation, if present (P)	Indicates pinch pressure

Thus, 3SP indicates a total of three rolls in an S-shape with tangential pressure (pinch or nip) on the final roll (see Figure 4).

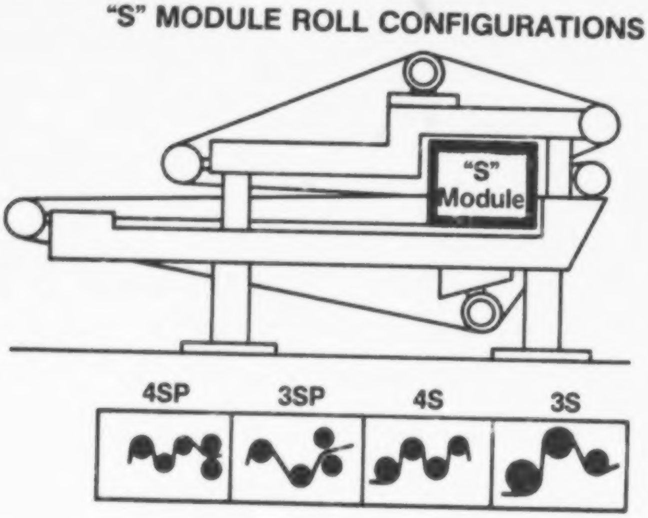

Figure 4. Typical Roll Configuration Variations Used in the "S" Module

The materials to be dewatered were thickener underflow slurries at both the blast furnace and BOP. During each trial, the blast-furnace or BOP slurry was pumped from the gravity thickeners to the feed box of the press. To adjust the feed rate, some of the slurry flow was diverted back to the thickeners. Each feed was characterized for solids content, ash content, pH, specific gravity, and particle-size distribution in accordance with standard test methods.

Generally, the trial schedule was conducted as follows:

Day 1	Set up press, make hook-ups, and check out systems. Begin polymer testing.
Day 2	Finish determination of polymer type and approximate dosage.

Day 3	Study effects of feed rate, belt speed and tension, roll configuration. Fine tune polymer dosage.
Day 4	Demonstration trial over eight-hour shift.
Day 5	Shut-down, dismantle, and ship out press.

RESULTS - BLAST-FURNACE TRIAL

The thickener underflow slurry from the blast-furnace wastewater-treatment system used as feed to the belt press was characterized as shown in Table I. Typically, the slurry was roughly 20 to 25 percent solids, had a relatively low specific gravity (1.1 - 1.2), had an ash content of 62.8 percent, was somewhat alkaline (pH = 8.2), and contained a considerable amount of fine particles (75 percent less than 325 mesh).

TABLE 1. CHARACTERISTICS OF FEED TO BELT PRESS

	Mesh	Blast-Furnace Feed Slurry	BOP Feed Slurry
Solids Content, percent		20-25	32-41
Ash Content, percent		62.5	98.2
pH		8.2	10.5
Specific Gravity		1.1-1.2	1.3-1.4
Particle-Size Distribution, weight percent			
	+60	0.2	0.2
	+100	2.1	0.6
	+200	12.1	2.0
	+325	8.9	3.2
	-325	76.7	94.0

Operating data from the blast-furnace sludge dewatering trials are shown in Table II. Tests 1 through 13 were performed to establish the optimum operating conditions and, as such, some of these results were not representative of the best operation. Feed percent solids varied from 20.3 to 24.9 during testing. At the optimum feed rate of 18 gallons per minute (gpm), throughput was about 1.2 dry tons per hour. The most effective polymer of those tested was polymer B, an anionic type, and was used in further testing and in the demonstration trial. The optimum polymer feed rate was about 0.8 gpm or 1.6 pounds of dry ton of solids (the concentration of the polymer feed was 0.5 percent in water). Addition of pinch rolls and/or increasing linear pressure increased the cake solids but at the expense of lower throughput rates and extrusion of solids through the belt. The 3S roll configuration was chosen as optimum. Feed rates up to 20 gpm were ideal for S-curve roll configurations (3S) but not for pinch rolls (3SP). Optimum belt speed was 9 feet per minute (ft/min) and belt tension was 48 pounds per linear inch.

TABLE 2. BELT-PRESS OPERATING DATA FOR BLAST-FURNACE SLUDGE DEWATERING

Run Test No.	Flow Rate of Feed, gpm	Solids Content of Feed, wt %	Throughput, dry tons/hr	Belt-Wash and Filtrate Suspended Solids, wt %	Polymer Type	Polymer Consumption, lb/dry ton of solids	Module Type & Nip Pressure, if applicable	Belt Speed, ft/min	Belt Tension, lb/linear inch		Cake Solids, wt %
									Top	Bottom	
1	11	23.1	0.74	0.08	A	2.6	3S	4.8	60	60	65.1
2	11.4	21.1	0.66	0.08	B	1.4	3S	4.8	60	60	66.5
3	11.4	21.5	0.66	0.07	C	1.9	3S	4.8	60	60	65.4
4	11	20.3	0.63	0.06	B	1.3	4S	4.8	60	60	67.5
5	15	21.1	0.89	0.08	B	2.0	3S	7	60	60	67.1
6	18	21.8	1.09	0.07	B	2.2	3S	9	60	60	66.1
7	22.3	21	1.30	0.16	B	2.2	3S	11.5	42	42	61.9
8	17.6	20.3	0.99	0.16	B	1.6	3S	9	38	38	63.7
9	9.6	21.6	0.58	0.24	B	1.4	3SP 95	4.8	60	60	71.8
10	9.6	20.5	0.55	0.12	B	2.0	3SP 95	4.8	60	60	70.4
10A	9.6	21.6	0.58	0.12	B	1.9	3SP 335	4.8	60	60	73.0
10B	9.6	21.6	0.58	0.12	B	1.9	3SP 205	4.8	60	60	71.6
10C	9.6	21.6	0.58	0.12	B	1.9	3SP 130	4.8	60	60	70.3
11	17.9	21.6	-	0.10	B	2.1	3S	9	38	38	67
12	22	21.8	-	0.16	B	2.3	3S	11.0	38	38	63
13	22	21.8	-	0.10	B	2.6	3S	11.5	38	38	61.7
14	18	23.7	1.22	0.11	B	1.7	3S	9	48	48	65.5
15	18	23.2	1.18	0.32	B	1.7	3S	9	48	48	67.8
16	18	24.9	1.27	0.10	B	1.6	3S	9	48	48	66.2
17	18	24.9	1.27	0.14	B	1.6	3S	9	60	60	68.4
18	18	24.2	1.25	0.33	B	1.6	3S	9	60	60	69.3
19	18	23.2	1.17	0.14	B	1.7	3S	9	60	60	68.4
20	18	23.2	1.16	0.13	B	1.7	3S	9	60	60	69.1

Tests 14 through 20 were performed as a demonstration trial at the optimum levels of operating parameters established in tests 1 through 13. These parameters as described above and summarized in Table III, were held constant over an eight-hour period.

TABLE 3. SUMMARY OF OPTIMUM BELT-PRESS PARAMETERS
BLAST-FURNACE SLUDGE DEWATERING

Feed Rate, gpm	18
Throughput, dry tons/hr	1.2
Polymer Type	B (anionic)
Polymer Flow, gpm	0.8
Polymer Rate, lb/dry ton of solids	1.6
Module Type	3S
Belt Speed, ft/min	9
Belt Tension, lb/linear inch	
Top	48
Bottom	48

During the demonstration trial, grab samples of filter cake were obtained at one-half hour intervals to measure the solids content. These results are shown in Table IV. Other than the first samples at 0930 (as start-up), the solids content of the filter-cake samples ranged between 67.2 and 70.2 percent with an average of 68.5 percent and standard deviation of 0.96 percent. At each of the times listed in Table IV, filtrate samples had solids contents less than 0.1 percent and the discharge from the press (filtrate plus belt-wash spray water) was between 0.1 and 0.3 percent solids.

TABLE 4. SOLIDS CONTENT OF FILTER-CAKE SAMPLES TAKEN AT HALF-HOUR INTERVALS DURING DEMONSTRATION TRIAL AT BLAST FURNACE

Time, hour of day	Solids Content of Filter Cake, wt %
0930	66.3
1000	67.6
1030	68.7
1100	68.0
1130	67.6
1200	68.6
1230	67.2
1300	67.6
1330	68.5
1400	70.2
1430	68.3
1500	69.0
1530	70.1
Average	68.5
Standard Deviation	0.96

RESULTS - BOP TRIAL

The thickener underflow slurry from the BOP wastewater-treatment system used as feed to the belt press had the characteristics given in Table I. Typically, the slurry had 32 to 41 percent solids, a specific gravity of 1.3 to 1.4, an ash content of 98.2 percent was very alkaline (pH = 10.5) and contained an extreme amount of fine particles (over 90 percent less than 325 mesh).

Operating data from the BOP sludge dewatering trials are shown in Table V. Tests 1 through 12 were performed to establish the optimum operating conditions and again are not representative of the best operation. Percent solids varied from 32 to 41 during testing. At the optimum feed rate of 10.5 gpm, throughput was about 1.3 dry tons per hour. The most effective polymer was polymer C, an anionic type, and was used in further testing and in the demonstration trial. The optimum polymer feed rate was about 1.3 gpm or 2.6 pounds per dry ton of solids (the concentration of the polymer feed was 0.5 percent in water). As with the blast-furnace sludge, addition of pinch rolls and/or increasing linear pressure increased the cake solids but at the expense of throughput rate and extrusion through the belt. The 3S roll configuration was chosen as the optimum overall. Feed rates up to about 12 gpm were ideal for most roll configurations. Optimum belt speed was 7 ft/min and the belt tension was 60 pounds per linear inch.

TABLE 5. BELT-PRESS OPERATING DATA FOR BOP SLUDGE DEWATERING

Run Test No.	Flow Rate of Feed, gpm	Solids Content of Feed, wt %	Throughput, dry tons/hr	Belt-Wash and Filtrate Suspended Solids, wt %	Polymer Type	Polymer Consumption, lb/dry ton of solids	Module Type & Nip Pressure, if applicable		Belt Speed, ft/min	Belt Tension, lb/linear inch		Cake Solids, wt %
										Top	Bottom	
1	12.5	34.3	1.44	0.04	B	0.8	3S		4.8	50	60	69.0
2	11.5	35.6	1.39	0.06	C	3.5	3S		8	50	60	68.0
3	11.5	39.5	2.29	0.15	C	1.5	3S		7.3	60	60	68.4
4	15	36.7	1.87	0.06	C	1.9	3S		10.0	50	50	67.2
5	19.5	41.0	2.84	0.11	C	1.4	3S		11.4	38	38	65.4
6	9.8	32.7	1.06	0.12	C	2.2	3S		4.8	60	60	69.8
7	9.7	32.3	1.03	0.17	C	2.6	3S		4.8	60	60	70.5
7A	9.7	32.3	1.03	0.17	C	2.6	3SP	50	4.8	60	60	70.5
7B	9.7	32.3	1.03	0.17	C	2.6	3SP	100	4.8	60	60	71.8
7C	9.7	32.3	1.03	0.17	C	2.6	3SP	250	4.8	60	60	74.2
8	12	35.7	1.03	0.28	C	2.2	3SP	20	8.25	60	60	69
8A	12	35.7	1.46	0.28	C	2.2	3SP	60	8.25	60	60	70
8B	12	35.7	1.46	0.28	C	2.2	3SP	240	8.25	60	60	74.3
9	12	36.8	1.53	0.15	C	2.1	S3		8.25	60	60	69.2
10	12	35.5	1.46	0.09	B	2.3	S4		7	60	60	70.8
11	12	34.5	1.40	0.07	B	2.8	S4		7	60	60	70.8
12	12	35.3	1.40	0.06	C	2.7	S4		7	60	60	70
13	10.5	35.6	1.22	0.10	C	2.7	S4		7	60	60	71.6
14	10.5	35.6	1.22	0.12	C	2.7	S4		7	60	60	70.4
15	10.5	36.1	1.27	0.09	C	2.6	S4		7	60	60	71.2
16	10.5	36.1	1.27	0.17	C	2.6	S4		7	60	60	70.3
17	10.5	36.4	1.30	0.04	C	2.4	S4		7	60	60	69.6

Tests 13 through 17 were performed as a demonstration trial at the optimum operating parameters established in tests 1 through 12. These parameters, as described above and summarized in Table VI were held constant over an eight-hour period.

TABLE 6. SUMMARY OF OPTIMUM BELT-PRESS PARAMETERS BOP SLUDGE DEWATERING

Feed Rate, gpm	10.5
Throughput, dry tons/hr	1.3
Polymer Type	C (anionic)
Polymer Flow, gpm	1.3
Polymer Rate, lb/dry ton of solids	2.6
Module Type	4S
Belt Speed, ft/min	7
Belt Tension, lb/linear inch	
Top	60
Bottom	60

Grab samples of filter cake were obtained at one-half hour intervals to measure the solids content. These results are shown in Table VII. The solids content of the filter-cake samples ranged between 70.2 and 72.4 percent with an average of 71.1 percent and standard deviation of 0.71 percent. At each of the times listed in Table VII, filtrate samples had solids contents less than 0.1 percent and the discharge from the press (filtrate plus belt-wash spray water) was between 0.1 and 0.4 percent solids.

TABLE 7. SOLIDS CONTENT OF FILTER-CAKE SAMPLES TAKEN AT HALF-HOUR INTERVALS DURING DEMONSTRATION TRIAL AT THE BOP

Time, hour of day	Solids Content of Filter Cake, wt %
0930	70.2
1000	72.1
1030	71.4
1100	71.4
1130	71.0
1200	72.4
1230	71.0
1300	70.4
1330	70.4
1400	70.6
1430	70.8
Average	71.1
Standard Deviation	0.71

RESULTS AND COMPARISONS

Rigid, semi-dry filter cakes were produced by the belt press from both the blast-furnace and BOP sludges during field trials. The filter cakes released readily at the discharge of the press as shown in Figure 5. No difficulties were experienced with the operation of the belt-press (e.g., belt tracking, blinding, or wear). The spray wash system was very effective in totally cleaning the belt. During the demonstration trials, once the operating conditions were set, little operator attention was required. The solids content of the belt-wash and filtrate water never exceeded 0.4 percent for either trial. Solids capture was 98 to 99 percent at the blast furnace and greater than 99 percent at the BOP.

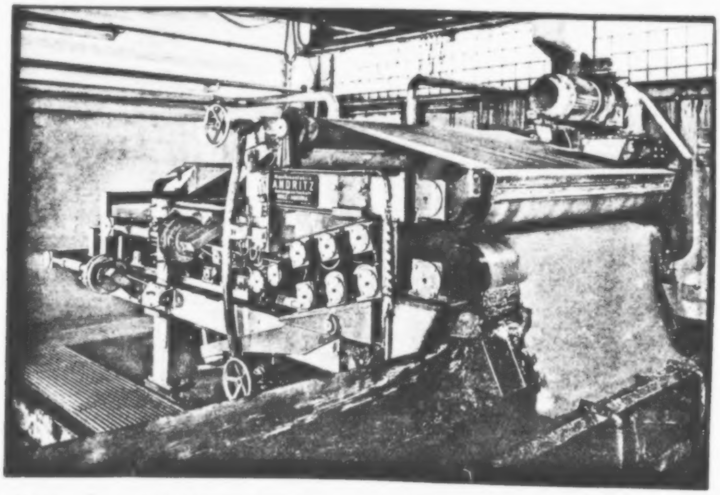

Figure 5. Filter Cake Discharge From Belt Press at Blast-Furnace Sludge-Dewatering Trial

Ash content of the dried cake was essentially the same as that of the slurry feed and there were no significant differences in particle-size distribution between filter cake and feed slurry. The blast-furnace cake was very rigid and difficult to penetrate while the BOP cake could be distorted somewhat but was still considered "firm". The large piles of filter cake generated at both sites could easily support the weight of a person standing on them.

Several relationships between the operational parameters and performance as measured by cake solids were observed:

1. Cake solids decreased as the belt speed increased (Figure 6). Increasing the belt speed reduced the length of time that the sludge was under pressure resulting in the removal of less water from the slurry.

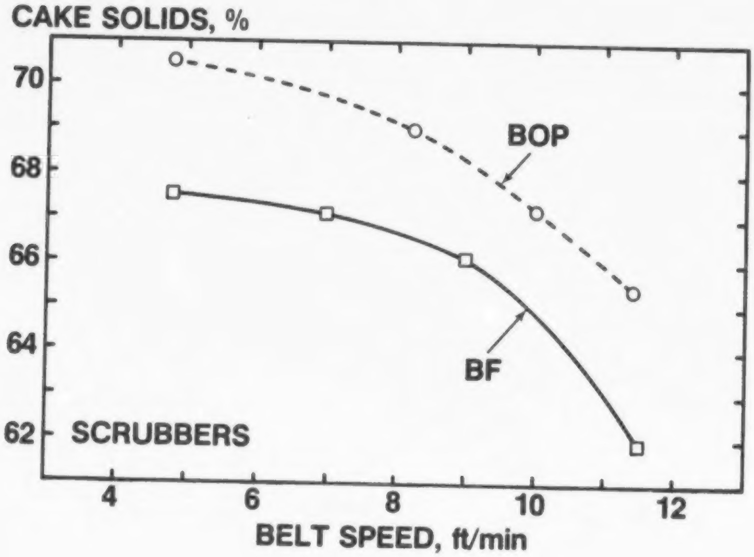

Figure 6

2. Cake solids increased when the belt tension was increased (Figure 7). By increasing the belt tension, the tangential pressure applied to the sludge by the belts was increased causing more liquid to be squeezed out of the slurry.

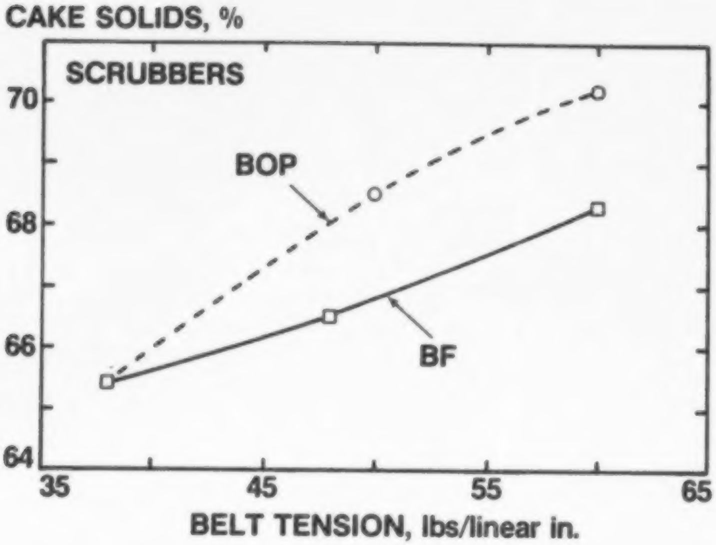

Figure 7

3. Cake solids increased with an increase in the nip or linear pressure PLI, (lb per linear inch) as shown in Figure 8. The results show that increasing the linear pressure on the blast-furnace slurry from 95 to 335 PLI increased the cake solids from 70.4 to 73.0 percent. For the BOP slurry, an increase of the PLI

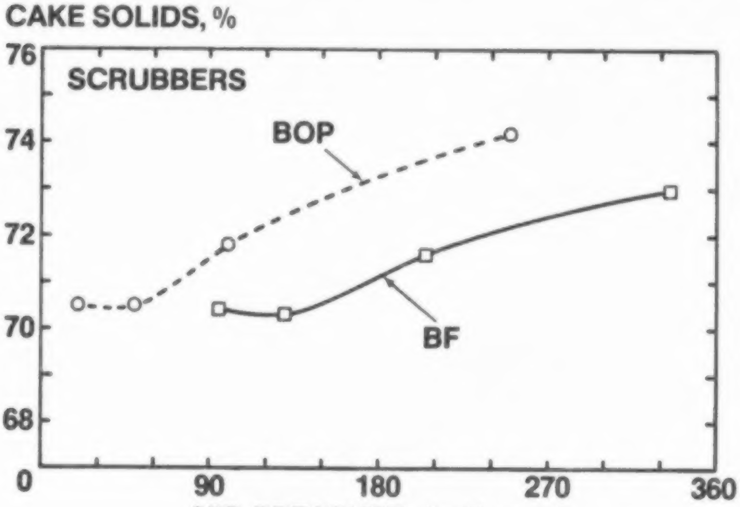

Figure 8

from 20 to 250 resulted in cake solids increasing from 70.5 to 74.2 percent. However, the maximum PLI of this machine for extended operation is 190. At this setting, the expected cake solids of the blast furnace and BOP slurries would be 71.4 and 72.5 percent, respectively. Since these cake solids are only marginally higher than those produced without nip pressure and to lengthen the belt life, no linear pressure is recommended for these slurries.

CONCLUSIONS

The following conclusions were established from the field trials.

1. Rigid filter cakes were consistently produced with cake solids averaging 69 percent for the blast furnace and 71 percent for the BOP sludge.

2. Polymer requirements ranged from about 1.6 pounds per ton (lb/ton) of dry solids for the blast-furnace sludge to about 2.6 lb/ton for the BOP sludge.

3. The one-half-metre press routinely processed sludge at a rate of 1.2 dry tons per hour for blast-furnace sludge and 1.3 dry tons per hour for the BOP sludge.

4. No cake release, belt-tracking, or other equipment problems were encountered. The spray wash system was very effective in cleaning the belt.

5. The combined belt-wash and filtrate discharge water from the press (to be returned to the clarifier) typically averaged about 0.1 percent solids and never exceeded 0.4 percent solids.

6. Relationships were established between certain operational parameters and performance parameters (cake solids). However, belt-press operation was not degraded by minor fluctuations in most operating parameters. Few equipment adjustments (and hence, little operator attention) would be required.

This study has demonstrated that belt-press filtration is capable of dewatering sludges from blast-furnace and BOP operations and has established the process parameters required for successful operation.

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RECYCLE OF ELECTRIC ARC FURNACE
EMISSION CONTROL DUST
EVALUATION OF A TWO YEAR PROGRAM

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Abstract

After a period of preliminary testing, Babcock & Wilcox began a standard procedure of recharging EAF dust into its Electric Arc Furnaces (EAF) in March 1982. This program is still ongoing.

This paper presents both qualitative and quantitative information used by Babcock & Wilcox in assessing and revising its program. Several physical formats for EAF dust recycle have been tested by Babcock & Wilcox prior to development of the briquette form presently being used. The parameters considered in making evaluations will be discussed.

Introduction

During the production of steel in electric arc furnaces (EAF) a metallic fume is generated from the scrap charging, melting and tapping cycle of furnace operations. Historically this material was emitted to the atmosphere through the ventilators on steel melt shop roofs. With the advent of air pollution control laws and regulations in the late 1960's it became necessary to collect and control this emission source. Primarily, steel manufacturers selected fabric filter collectors as the means to cost effectively control these dry particles. With the advent of baghouse control facilities on EAF furnaces and melt shops, what had been considered an air pollution problem now became a byproduct or waste requiring some form of material handling.

As a byproduct, this material was frequently accumulated on steel making sites when space permitted it. When managed as a waste, it was combined with other steel making wastes and landfilled.

B&W began control of its EAF melt shop emissions in July 1972, and managed its emission control dust in the same manner until initiation of its recycle investigation program in September 1981. The advent of U.S. EPA's hazardous waste regulations in May 1980 effected the management of this byproduct at all steel melting operations in the United States.

Background

B&W operates three (3) steel melting shops near Beaver Falls, Pennsylvania, and recently began operation of a fourth shop in February 1984. As indicated in Figure 1, B&W implemented the handling procedure for the byproduct material upon startup of the baghouse collectors in July 1972.

The system to service the existing melt shops uses a completely sealed shop roof with roof canopy hoods located over each furnace for control of all charging, melting and tapping emissions. The control devices are positive pressure, reverse air cleaned, baghouses. The melt shops and associated emission control systems are configured as follows:

TABLE 1 - ELECTRIC ARC FURNACE CONFIGURATION

WALLACE RUN STEEL MILL

	No. 1 Melt Shop	
2 - 25 Ton EAF's	to	No. 1 Baghouse
	No. 2 Melt Shop	
1 - 50 Ton EAF 1 - 75 Ton EAF	to	No. 2 Baghouse
	AOD* Shop	
1 - 25 Ton Vessel	to	No. 2 Baghouse

KOPPEL STEEL MILL

	No. 3 Melt Shop	
1 - 50 Ton EAF 1 - 75 Ton EAF	to	No. 3 Baghouse
1 - 100 Ton EAF	to	No. 4 Baghouse
2 - 100 Ton EAF's	to	No. 5 Baghouse

*Argon Oxygen Decarburization (AOD)

The fume collected from the five baghouses servicing the melt shops is unloaded from the baghouse hoppers into pneumatic tanker trailers. The trailers are taken from each location to a pelletizing plant located at B&W's Koppel Operations, approximately 5½ miles from Wallace Run Steel Mill and one-half mile from Koppel Steel Mill No. 3 Melt Shop. At the pelletizing plant the dust is pneumatically conveyed to a storage silo, from which it is fed into a disk pelletizing machine. Water is the only substance mixed with the dust for agglomeration into pellets. The pellets range in size from 1/4" to 3/4" in diameter. From the discharge of the disk the pellets are conveyed to a storage pile adjacent to the pellet plant. The use of the pellet pile as the normal path of pellet handling was discontinued in March 1982.

During the period of July 1972 to March 1982, the EAF dust collected at the baghouses is characterized by the general analysis presented in Table 2.

TABLE 2 - EAF DUST CHEMICAL ANALYSIS BY SOURCE (%)

COMPONENT	NO. 1 B.H.	NO. 2 B.H.	NO. 3&4 BH*	NO. 5 BH
Fe_2O_3	63	67	68	67
CaO	5.57	2.94	3.81	3.58
Al_2O_3	1.24	1.32	1.08	1.24
SiO_2	4.7	6.6	1.9	1.9
MgO	11.76	8.58	9.58	11.88
Mn	0.7	0.9	0.9	0.9
ZnO	2.46	3.42	7.30	6.29
NiO	1.16	0.04	0.13	0.10
Cr_2O_3	1.9	0.4	1.3	0.6
CuO	0.12	0.11	0.14	0.13
MoO_3	1.24	0.63	1.1	0.8
PbO_2	0.45	0.71	1.8	1.4
BiO_2	0.06	0.04	0.05	0.05

*Discharge hopper combines the dust collected from both baghouses.

The significant items immediately evident from this analysis are:

- The dust is higher in Fe_2O_3 than normally associated with EAF emissions.

- The ZnO and PbO_2 are lower than normally associated with EAF emissions.

- The NiO and Cr_2O_3 levels are low.

- The CaO is lower than normally associated with EAF emissions.

These factors are significant and important for several reasons. First, the ZnO level is very low and does not make the dust attractive for byproduct recovery in the Zinc recovery industry. Second, the levels of NiO and Cr_2O_3 are also too low to process the dust for stainless steel remelt alloy. Third, the Fe_2O_3 is so high that it is potentially attractive for only its iron units. It is this factor combined with others that originally caused B&W to consider the material as a future resource, and to begin with agglomeration and storage of the material.

The low level of CaO in the dust allows use of water as a binding agent. Subsequent investigations have shown that free lime in excess of 10-12% in a dust will cause the pellets to break down within a few days of curing.

There are several reasons why the B&W dust is of this nature:

- B&W does not operate a fourth hole evacuation system on any of these furnaces. This reduces the amount of lime in the dust.

- B&W previously melted the greatest cross-section of alloy specifications in the industry. Stainless steel is only a small part of this business.

- B&W selectively purchases its scrap, eliminating nearly all galvanized and terne metal contamination.

Normally the incentive to investigate recycle of the emission dust would be associated with the value of iron units in scrap steel. The economic equation favoring recovery of the iron units in the dust was altered by the U.S. EPA determination that EAF emission control dust was a generic, listed hazardous waste in May, 1980.

Preliminary Recycle Program

B&W began an independent investigation of the practicality of EAF dust reclamation and reuse shortly after EPA's rules were published in May 1980. Independent investigations were suspended in 1980 to allow for active participation in the EAF emission dust study being funded by AISI and the Department of Commerce at Lehigh University. The investigations and results of that study[1] provided the basis for B&W proceeding into a test program in August 1981.

In the test program several preliminary objectives were considered as decision points on whether to proceed with a full-scale recycle program.

- The effect of pellet charging on the shop atmosphere.
- Amount of lead contributed to the shop atmosphere.
- Effect on furnace target chemistry.
- Effect on electrode consumption.

These points were considered as kill items for a full-scale program if they presented unreasonable problems in a test program. Two one-week campaigns using both No. 6 and No. 7 furnaces (No. 5 B.H.) in No. 3 Melt Shop were selected as the test period. After establishing shop atmosphere characteristics for TSP and lead prior to the test period, all heats during this period were charged with 2000-2500 pounds of pellets. The second scrap charge bucket was selected as the mechanism for charging the pellets into the furnace.

During the test period, shop atmosphere characteristics did not change significantly with respect to TSP or lead. Samples of EAF dust taken from the baghouse were analyzed to see if any change could be detected. Table 3 describes the range of components in the dust during the two test periods, the weeks of August 12 and September 8, 1981.

TABLE 3 - PRELIMINARY TEST - EAF DUST ANALYSES (%)

COMPONENT	RANGE AUGUST, 1981*	RANGE SEPTEMBER, 1981**
Fe_2O_3	60.9 - 62.9	61.5 - 63.0
CaO	12.9 - 14.5	12.1 - 13.0
SiO_2	4.0 - 4.8	4.5 - 4.7
Cr_2O_3	1.5 - 1.9	1.5 - 1.7
NiO	.05 - .07	.03 - .04
ZnO	2.4 - 3.0	2.7 - 4.5
CuO	.13	.18 - .28
Al_2O_3	.76 - .79	.76 - .85
CdO	$<$.01	$<$.01
MgO	5.9 - 6.1	5.2 - 5.8
MnO	5.2 - 5.3	5.5 - 5.7
MoO_3	.14 - .23	.15 - .20
PbO_2	.81 - .86	.86 - 1.03

* 3 samples during week of August 12, 1981

** 3 samples during week of September 8, 1981

Slag samples were also collected from the heats run during this period. The range and average values for slag chemistries during this test period are listed in Table 4. Since slag chemistries were generally in the range to be expected for the steel grades being melted, no particular trend could be forecasted. It did confirm that very little, if any, zinc or lead was being picked up in the slag. Although the EAF dust characteristics did not indicate a notable increase in zinc or lead, it was expected that these would tend to increase at an, as yet, unquantified rate.

TABLE 4 - PRELIMINARY TEST - EAF SLAG CHEMISTRY (%)

	AUGUST 1981 *		SEPTEMBER 1981 **	
COMPONENT	RANGE	AVG.	RANGE	AVG.
FeO	7.27-17.21	9.77	8.90-16.43	11.33
Fe_2O_3	3.35-11.52	3.68	0.64-11.42	6.67
ZnO	<.05	<.05	<.05	<.05
SiO_2	14.91-30.25	20.41	14.86-22.90	20.98
CaO	26.69-48.48	36.46	22.04-40.58	29.74
PbO	<.01	<.01	<.01	<.01
Cr_2O_3	0.74- 2.47	1.66	0.73- 9.61	3.23
NiO	<.01	<.01	<.01	<01

* 8 slag samples during week of August 12, 1981

** 9 slag samples during week of September 8, 1981

A review of melting logs for electrode time and furnace delays during this period did not exhibit any trend not already present in melting practice. Based upon the review of this data, and extensive shop atmosphere characterization, B&W concluded that the initial test criteria were positively satisfied. A decision to commit to a standard practice of pellet charging at No. 3 Melt Shop was made in March 1982.

Full-Scale Program - Phase I

Beginning in March 1982, all EAF dust generated at B&W melt shops was pelletized and returned to the No. 3 Melt Shop for charging with scrap into the five (5) furnaces. During this period of activity several factors need to be identified with their effect on this program.

- The dust from Wallace Run Steel Mill was combined with No. 3 Melt Shop dust for this initial period.

  Since the alloy business level at that time caused the heats to be assigned throughout the steel facilities, no particular weighting of product was assigned to any one melt shop. The exception was stainless melting at No. 1 Melt Shop, less than 5% of the business at that time.

- Because B&W did not use a fourth hole furnace it was important to determine whether we were increasing the overall dust burden in the No. 3 Melt Shop.

  Tracking of the pounds of dust per ton of melted steel through 1981 showed relatively even loading at about 15-17 lb./ton of steel (Figure 2). This did not hold steady during the period following March 1982, when pellet charging became a standard practice. (Figure 2). Average pound per ton rates continued to climb to nearly 30 lb./ton of steel.

- The increase in dust generation rates did not have a significant effect on shop atmosphere quality even though lead levels in the dust continued to increase. Scrap practice changes were actually able to reduce employee exposure during this period.

- The level of dust generation appeared to be reaching a plateau by mid August 1982, when the level of melting activity degenerated with the extremely poor market conditions first felt in May 1982.

  The intermittent level of melting schedules beginning in September 1982, through March 1983, did not allow for effective characterization of the dust generation rate during that period (Figures 2 and 3).

- With the downturn in business activity, the levels of chromium and nickel began to increase in the dust being generated at Wallace Run Steel Mill.

  The No. 2 Melt Shop suspended activity during this period, and essentially the melting of stainless steel was conducted in No. 1 Melt Shop with AOD refining. Table 5 identifies the changing nature of dust collected at Wallace Run Steel Mill.

TABLE 5 - CHANGE IN EAF DUST AT WALLACE RUN STEEL MILL (%)

	PREVIOUS		JUNE 1982		AUGUST 1982		NOVEMBER 1982	
COMPONENT	NO. 1	NO. 2	NO. 1	NO. 2	NO. 1	NO. 2	NO. 1	NO. 2
Fe_2O_3	63	67	70	69	27	50	33	45
CaO	5.57	2.94	5.4	2.8	2.8	4.3	2.8	5.2
NiO	1.16	0.04	6.2	4.1	7.3	5.3	9.1	5.3
Cr_2O_3	1.9	0.4	1.9	3.8	12.6	14.4	10.5	11.0
ZnO	2.46	3.42	3.7	5.6	4.2	2.2	3.3	3.5
PbO_2	0.45	0.71	0.5	0.7	0.2	0.2	0.3	0.3

- During this period several investigations were made to improve pellet hardness by adding binders to the water being applied to the pelletizing disk (i.e., sodium silicate, dust agglomerators, organic polymers, etc.). The results of this testing indicated that significant increases in pellet hardness were not practical or achievable with binders.

- In an effort to recover the resources available from the accumulated pile, several test formats were applied to the previously pelletized dust.

  Several problems had to be overcome in re-using the pile material. Primarily these were associated with:

- Non-uniform density in the material pieces.
- Non-uniform moisture content.
- Non-uniform size of material.

Several tests of crushing and repelletizing the material were conducted. The single characteristic that had the most impact on satisfactory reformation was moisture content.

- During the period of pellet charging to No. 3 Melt Shop (No. 3, 4, and 5 baghouses) the level of zinc and lead oxide concentration increased in the dust being processed through the recycle loop. Table 6 identifies the changing nature of the recycle dust.

TABLE 6 - CHANGE IN EAF DUST AT NO. 3 MELT SHOP (%)

	PREVIOUS		JUNE 1982		AUGUST 1982		NOVEMBER 1982	
COMPONENT	NO.3&4	NO. 5	NO. 3&4	NO. 5	NO. 3&4	NO. 5	NO. 3&4	NO. 5
Fe_2O_3	68	67	65	69	30	32	40	40
CaO	3.8	3.6	3.7	3.9	8.3	10.2	7.9	6.9
NiO	0.1	0.1	.04	.05	.02	.03	.03	.03
Cr_2O_3	1.3	0.6	0.6	0.7	0.6	0.7	0.8	1.1
ZnO	7.3	6.3	27.4	18.7	26.7	21.3	21.6	19.1
PbO_2	1.8	1.4	2.4	2.2	3.5	3.0	3.5	3.2

Conclusions - Phase 1

During the period of the full-scale run on pellet charging to No. 3 Melt Shop, B&W came to some conclusions for modifying and improving the program.

The revision of melting at Wallace Run Steel Mill to nearly 100% stainless steel production needed to be modified. The increasing levels of Chromium and Nickel in the dust were a concern for steel metallurgy at No. 3 Melt Shop since it was committed to melting carbon and alloy steel grades. Further, the increased levels of these metals now made the dust attractive for the remelt alloy refining business. Heretofore, the dust had always been far too low in Nickel and Chrome to be usable in that process.

The increased level of zinc in the dust, associated with recycle, had achieved a level above what is considered attractive to the zinc refining industry (20% ZnO). It appeared that the zinc oxide level could be increased, but because of the irregular production levels the rate of increase could not be effectively established.

During this particular period, it was concluded that the water-bound pellet was not satisfactory as a means for recovering the dust stored in the pellet pile. Steel Operations was not particularly happy with the physical strength of the pellet for handling in the scrap charge. The increasing dust generation rate per ton of steel indicated that a portion of dust was being reentrained into the fume control system during scrap charge.

Recognizing these potentials for promoting an improved recycle process, B&W began a second phase of recycle that placed emphasis on developing an acceptable physical format for introducing EAF dust into the furnace.

Full-Scale Program - Phase II

The recycle program was modified during 1983 and incorporated the process flow outlined in Figure 4. This is essentially the same process that had been used in Phase I except that the stainless dust generated at Wallace Run Steel Mill was removed from the internal recycle loop. Stainless dusts were and are transported to the Inmetco process plant in Ellwood City, PA, where the material is processed into remelt alloy for reuse in No. 1 Melt Shop.

During the period from February 1983 through December 1983, melting operations continued in a depressed mode with some stability in the number of heats scheduled in No. 3 Melt Shop. As indicated on Figure 3, the average dust generation rate remained relatively stable through this period (15-20 lb. dust/ton steel). Contributing to this stability was the periodic introduction of a briquette form of EAF dust into the melting operations.

The briquette format for EAF dust reuse was initially adopted to reprocess the dust contained in the existing pellet pile. B&W began a joint investigation with Cametco, Inc. of Duquesne, PA, to reprocess the previously pelletized material. Beginning with trials of nearly 100% EAF dust in the briquette mixture, a final form was established as the best ratio for providing physical strength while maximizing the EAF dust concentration. This ratio is outlined in Table 7.

TABLE 7 - EAF DUST BRIQUETTE RATIO (%)

COMPONENT	PERCENT*
EAF Dust	50
Mill Scale	20
Grinding Swarf	15
Coke Breeze	10
Binder, etc.	5

*Target percent - May vary ± 5% in any one briquette.

For best penetration into the steel bath the briquettes are charged in the second scrap bucket. The bucket is made up such that the briquettes are loaded in the middle third of the bucket. Light scrap is in the lower third, and the upper third is made up of heavy scrap. The object of this practice is to maximize penetration into the molten steel bath present from the first scrap bucket, and avoid lead accumulation potential in the furnace bottom.

The briquette format for handling the EAF dust was considered as the best method for introducing the pellet pile material, and since it satisfied the physical requirements for durability in handling, the briquette was adopted as the method for handling all EAF dust recycled to No. 3 Melt Shop. The process diagram for this revision to the recycle program is outlined in Figure 5. B&W began this standard practice in December 1983. All EAF dust collected at No. 3 Melt Shop is directed to the B&W pelletizing plant, and the pellets, swarf and mill scale are sent to the Cametco plant for processing into the recharge briquette.

Beginning in February 1984, B&W started operation of a new melt shop (No. 4 Melt Shop) at its Koppel Operations. This facility has a single ultra high-powered (UHP) electric arc furnace (80 net tons) as its melting unit. The UHP furnace has a fourth hole fume evacuation system and is evacuated to the existing No. 4 Baghouse (previously servicing No. 3 Melt Shop).

Conclusions and Further Work

Based on the work done to date on internal recycle of EAF dust, B&W believes that the process flow diagram outlined in Figure 6 is an achievable method for handling dust that is generated, and reprocessing the storage pile material. To cost effectively manage this program, the following tasks remain to be accomplished before accurate economics and performance can be evaluated.

- Complete an effective program of briquette introduction into the No. 4 Melt Shop to realize the benefit of iron recovery in the steel bath and oxygen in the slag practice.

- Quantify the rate of ZnO increase per pound of dust charged per tons of steel melted to achieve +20% ZnO.

- The optimum charge weight of briquettes to achieve the maximum rate of ZnO while controlling iron and oxygen recovery.

- Engineer the process for introducing EAF dust in the dry form into the briquette formulation process.

Throughout this program the effect of pellet or briquette usage has been difficult to quantify as far as actual impact on electrode time or chemistry delays. The variability of steelmaking from heat to heat is full of situations that have a complex effect on melt times. It has been the opinion of Steel Operations management and supervision that the briquette practice has had minimal negative effect and offers a potential asset to steelmaking in UHP furnace practices.

The program is far from complete in maximizing efficiency in this reuse and recovery activity. It is B&W's opinion that innovative activity and engineering in this area of resource recovery will continue despite the regulatory disincentives and frustrations that continue to be placed on responsible resource recovery practices.

REFERENCES

1. Lehigh University. "Characterization, Recovery and Recycling of Electric Arc Furnace Dust". U.S. DOC Project No. 99-22-09886-10. February 1982.

Dust Process Diagram   Prior To Recycle

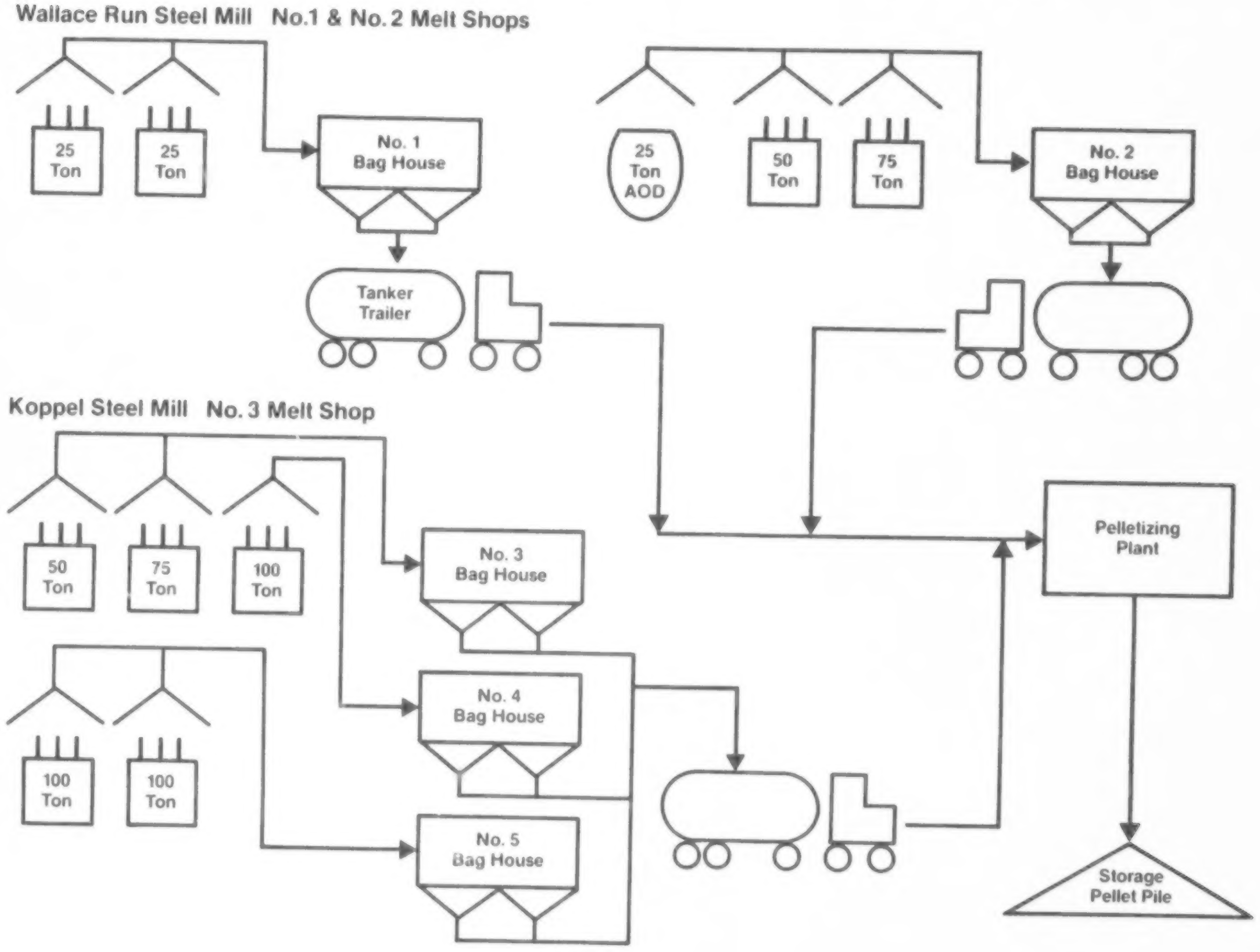
Wallace Run Steel Mill   No.1 & No. 2 Melt Shops
25 Ton
25 Ton
No. 1 Bag House
Tanker Trailer
25 Ton AOD
50 Ton
75 Ton
No. 2 Bag House
Koppel Steel Mill   No. 3 Melt Shop
50 Ton
75 Ton
100 Ton
100 Ton
100 Ton
No. 3 Bag House
No. 4 Bag House
No. 5 Bag House
Pelletizing Plant
Storage Pellet Pile

FIGURE 1

Dust Generation per Steel Production

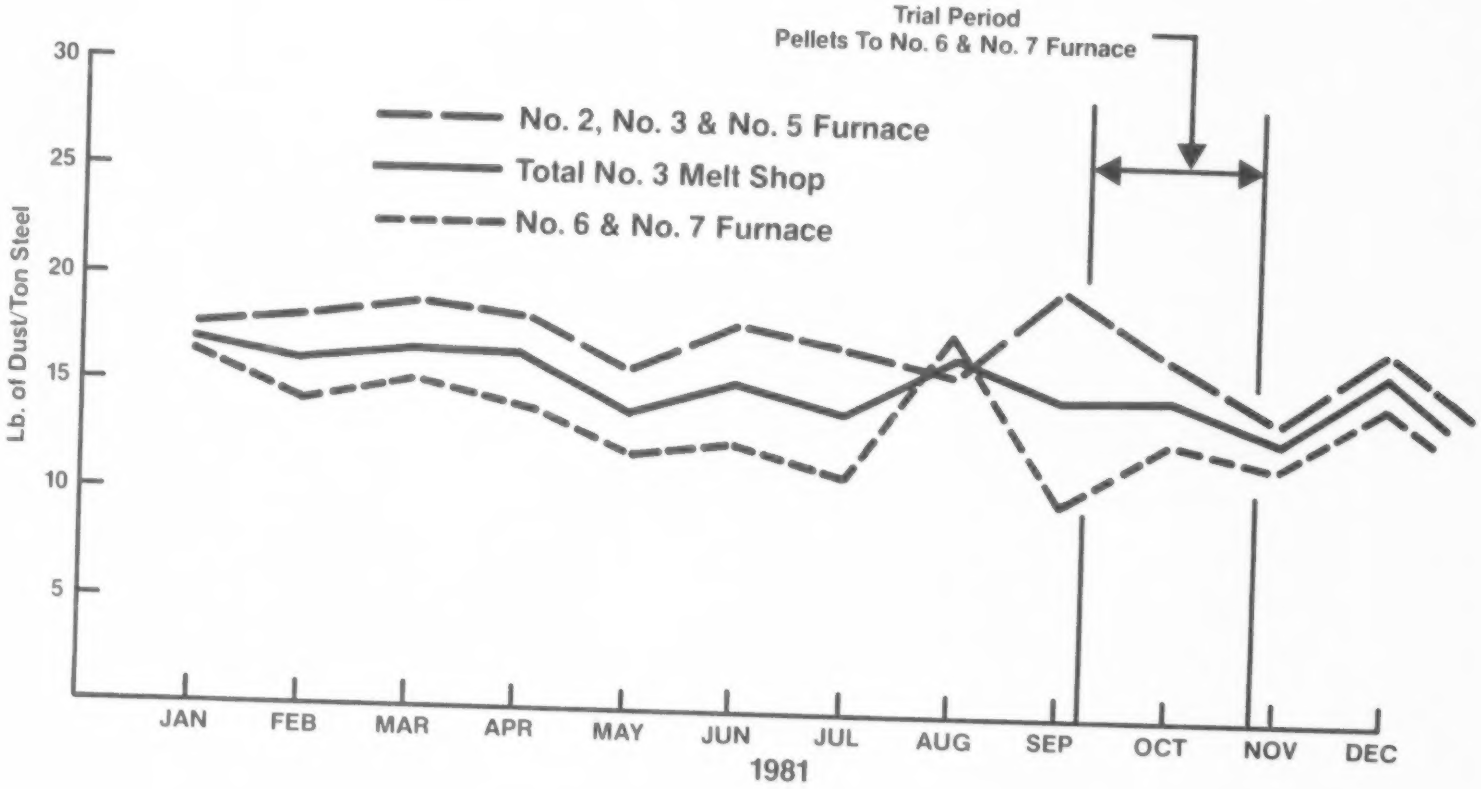

FIGURE 2A

Dust Generation per Steel Production

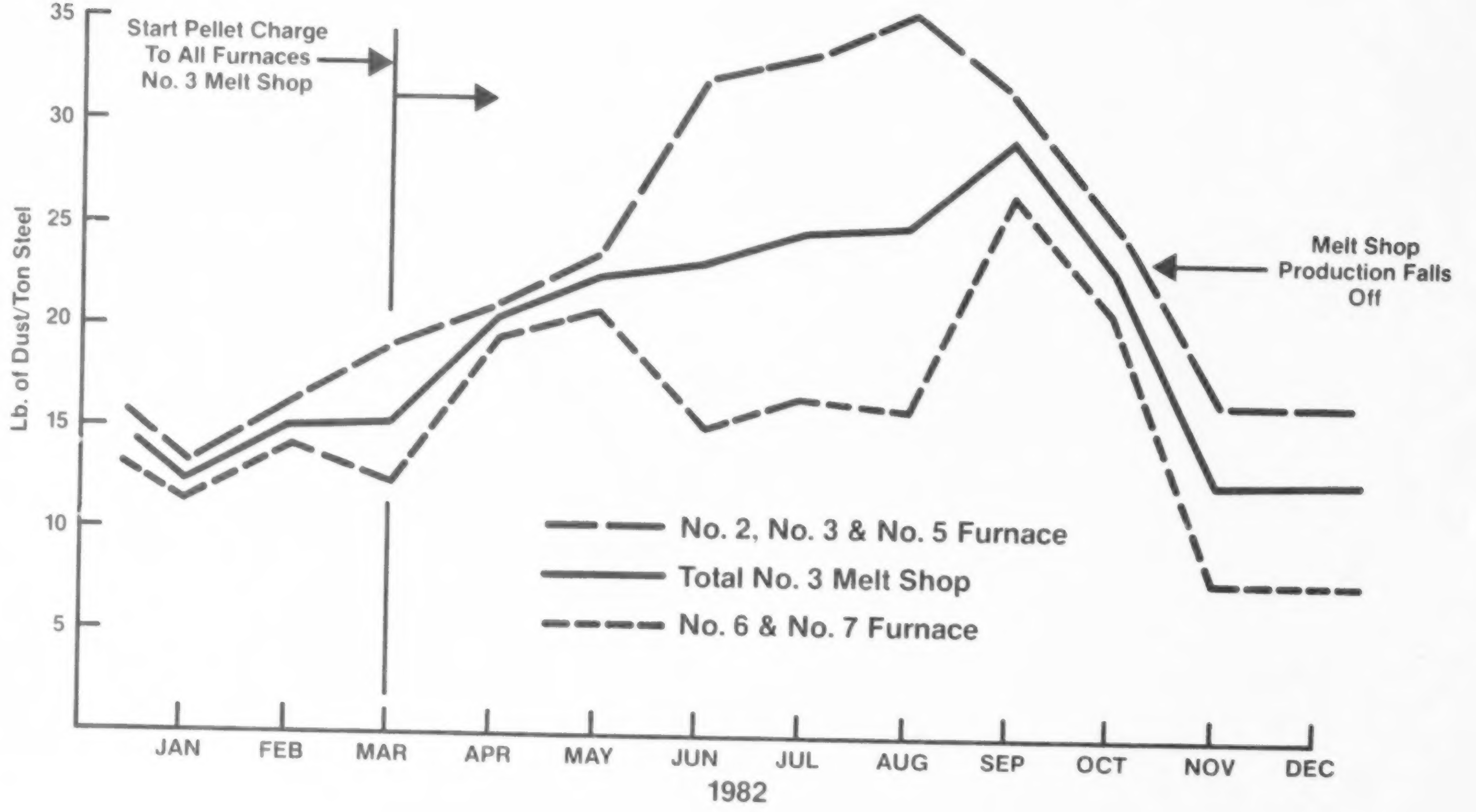

FIGURE 2B

Dust Generation per Steel Production

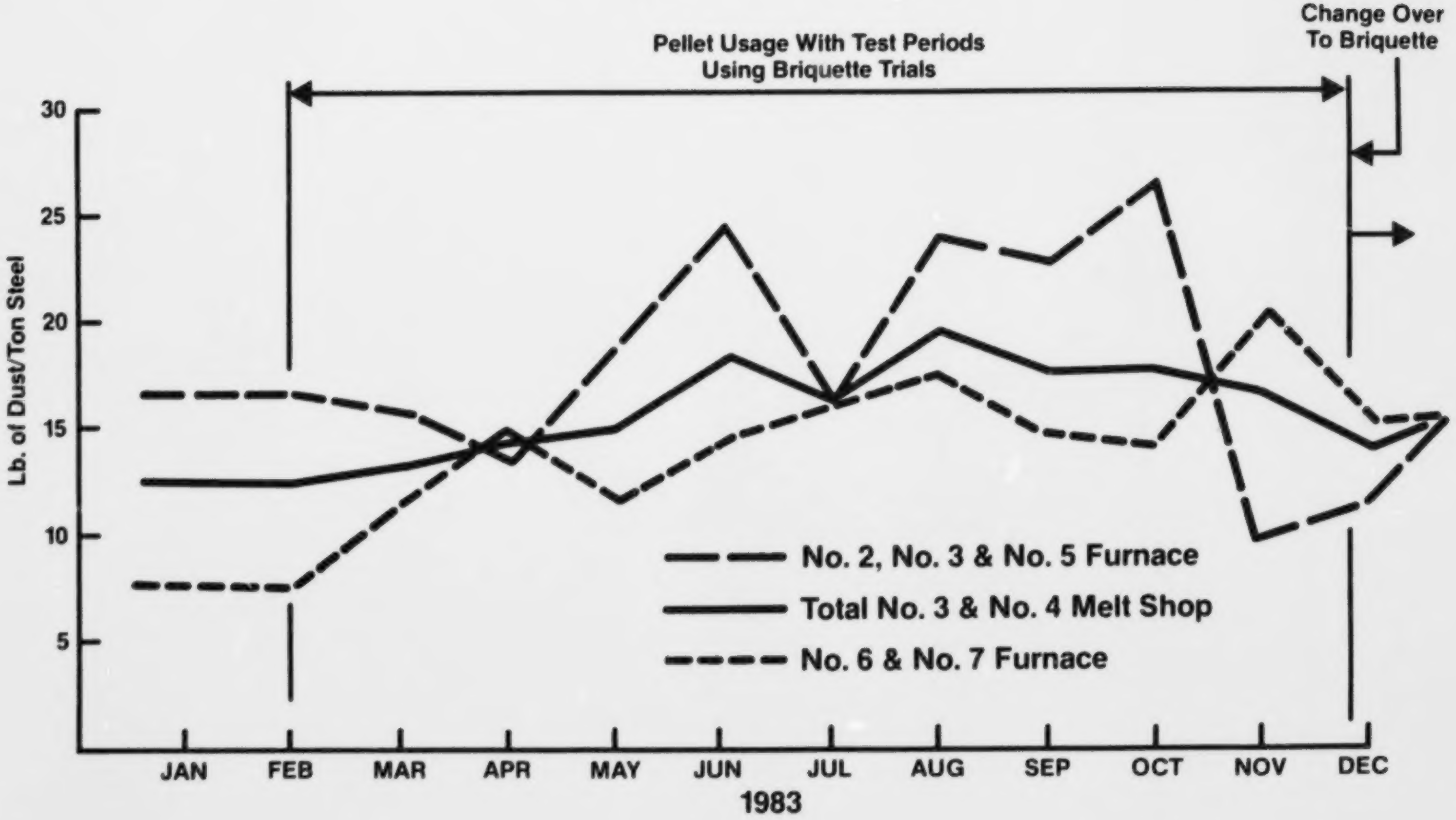

FIGURE 3A

Dust Generation per Steel Production

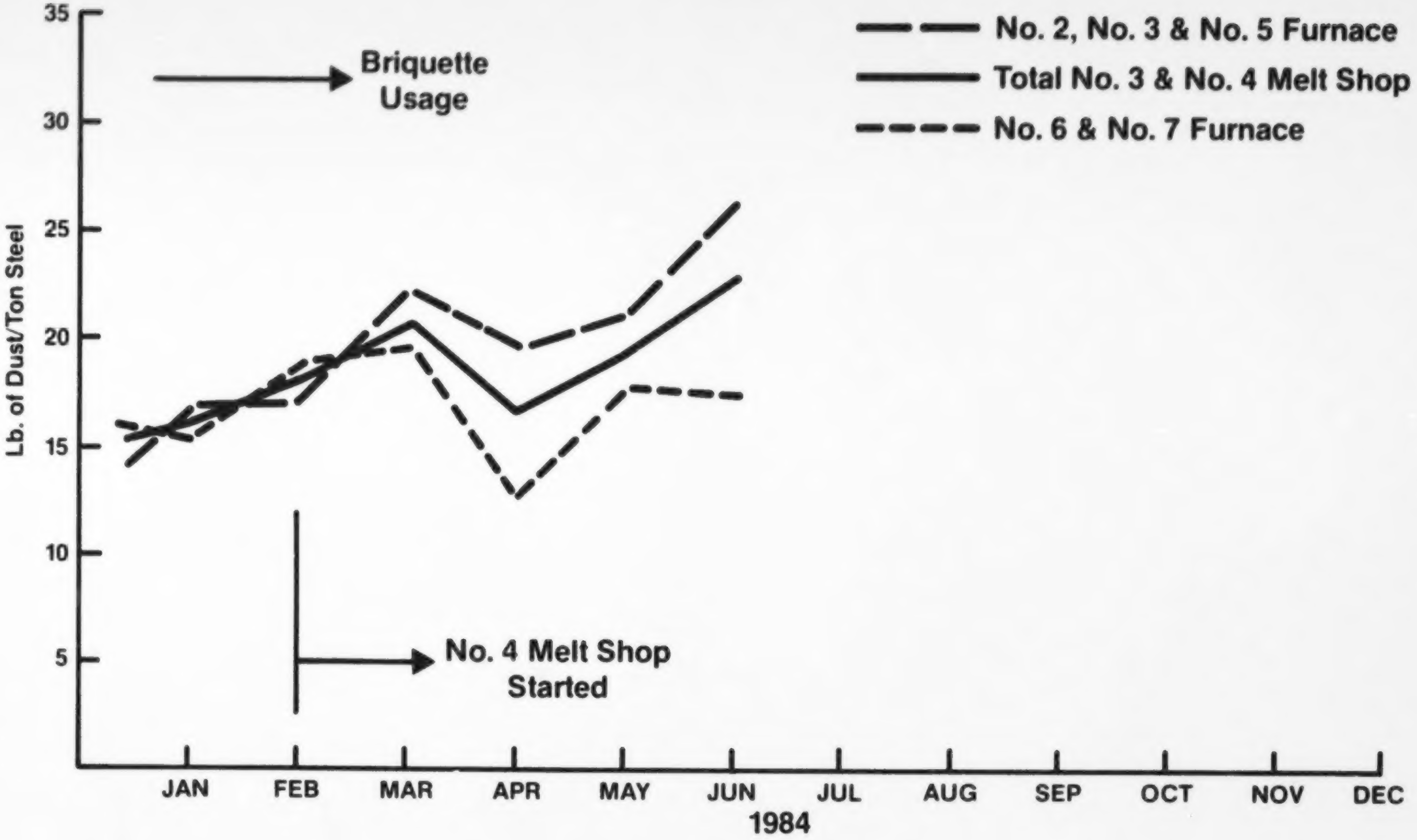

FIGURE 3B

Dust Process Diagram   Revised For Stainless Dust

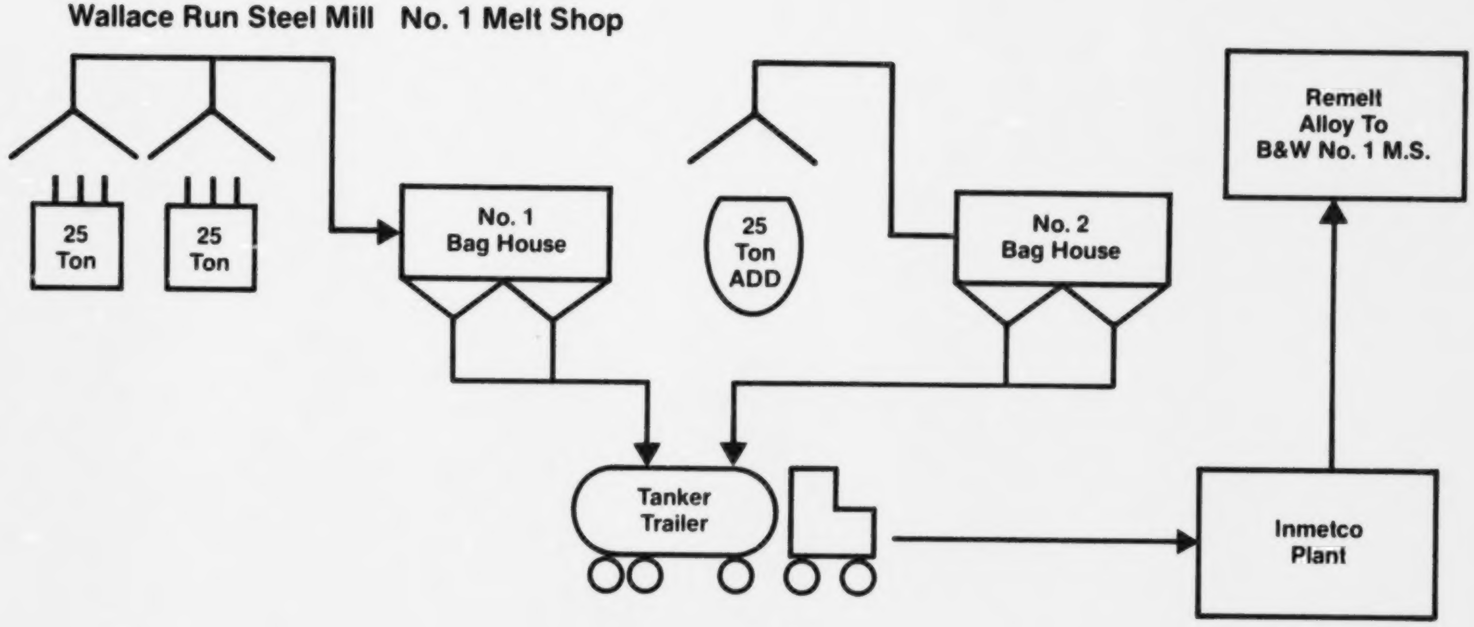
Wallace Run Steel Mill   No. 1 Melt Shop
25 Ton
25 Ton
No. 1 Bag House
25 Ton ADD
No. 2 Bag House
Remelt Alloy To B&W No. 1 M.S.
Tanker Trailer
Inmetco Plant

FIGURE 4A

Dust Process Diagram Revised For Stainless Dust

Koppel Steel Mill No. 3 Melt Shop

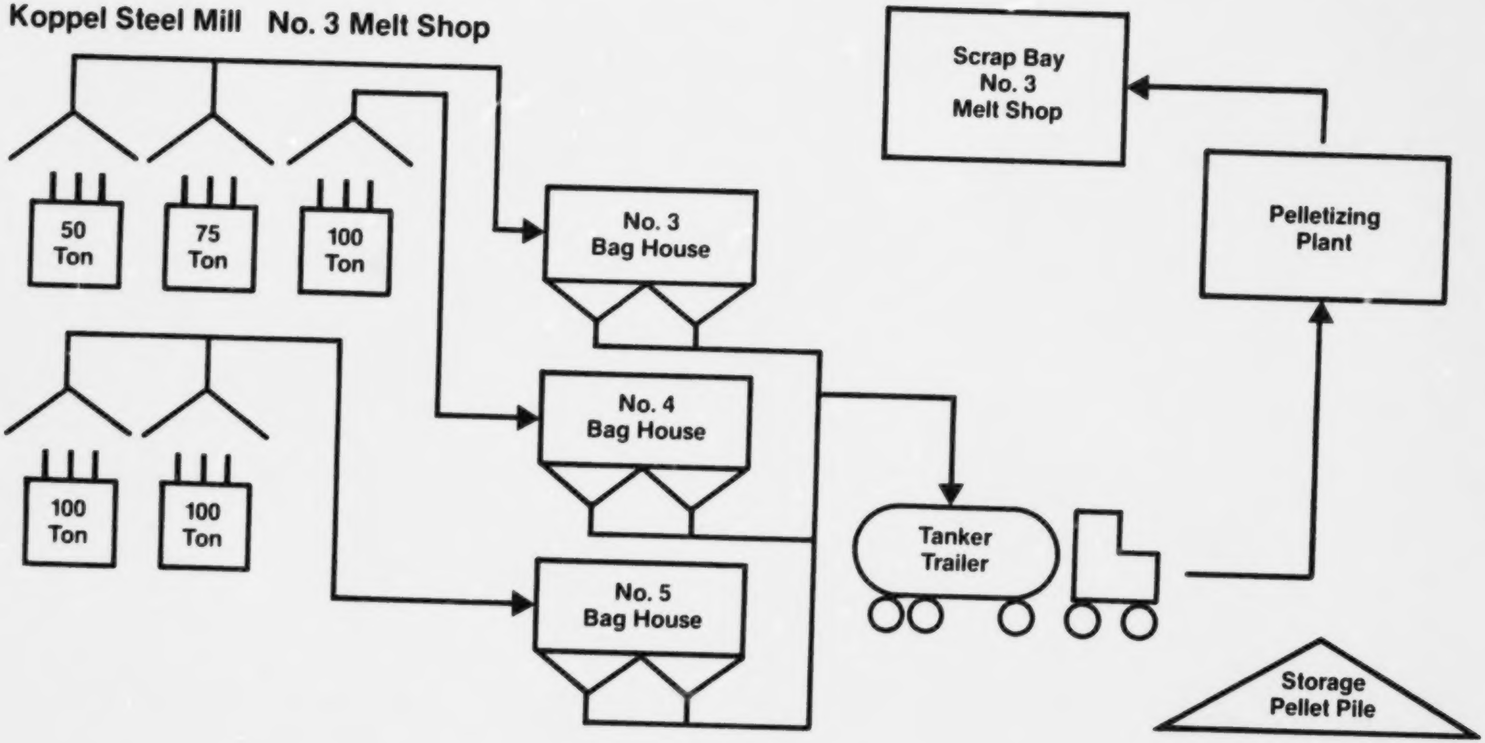
50 Ton
75 Ton
100 Ton
100 Ton
100 Ton
No. 3 Bag House
No. 4 Bag House
No. 5 Bag House
Tanker Trailer
Scrap Bay No. 3 Melt Shop
Pelletizing Plant
Storage Pellet Pile

FIGURE 4B

Dust Process Diagram Prior To No.4 Melt Shop

Koppel Steel Mill No. 3 Melt Shop

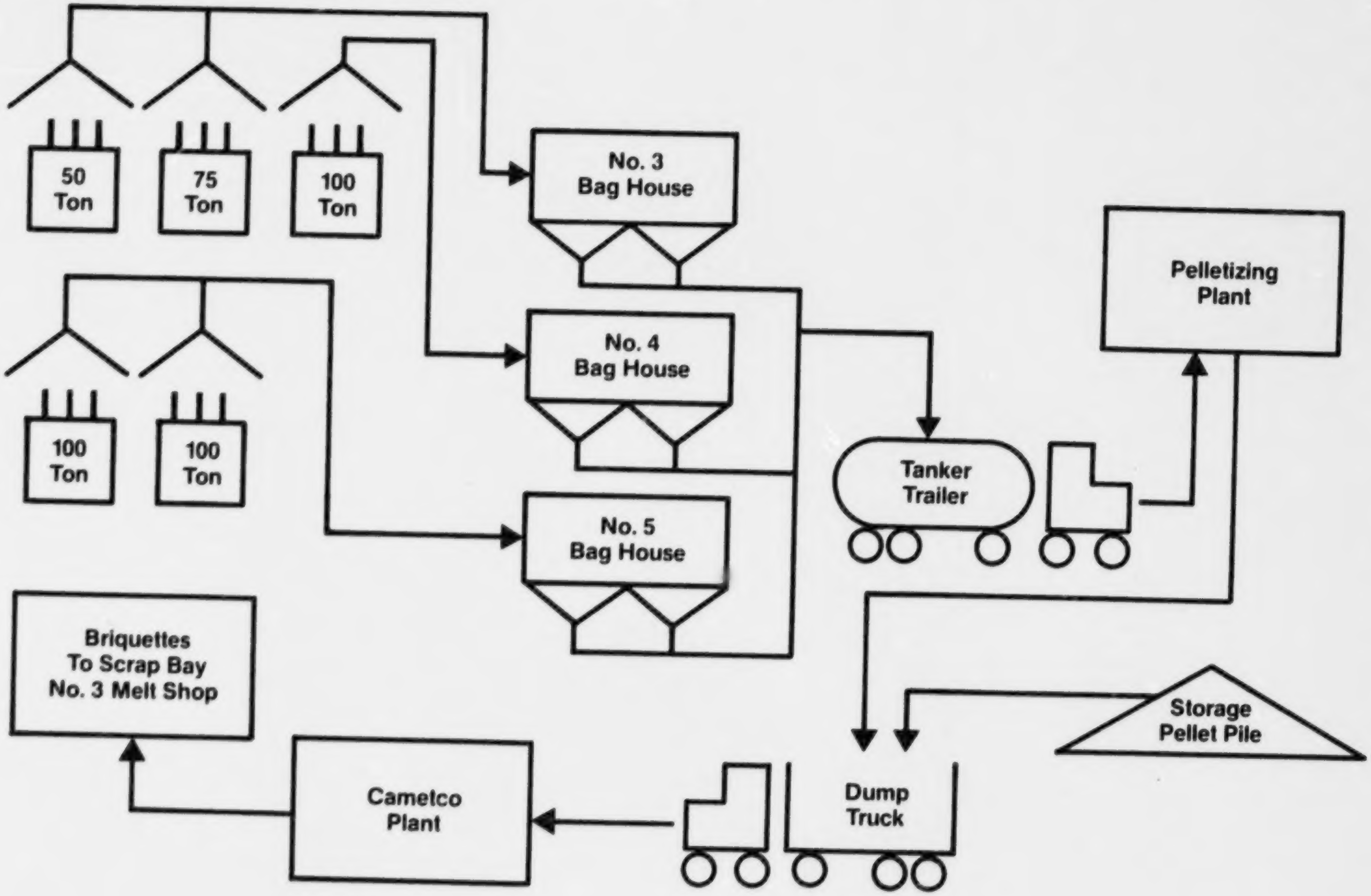
50 Ton
75 Ton
100 Ton
100 Ton
100 Ton
No. 3 Bag House
No. 4 Bag House
No. 5 Bag House
Tanker Trailer
Pelletizing Plant
Storage Pellet Pile
Dump Truck
Cametco Plant
Briquettes To Scrap Bay No. 3 Melt Shop

FIGURE 5

Dust Process Diagram Zinc Recovery

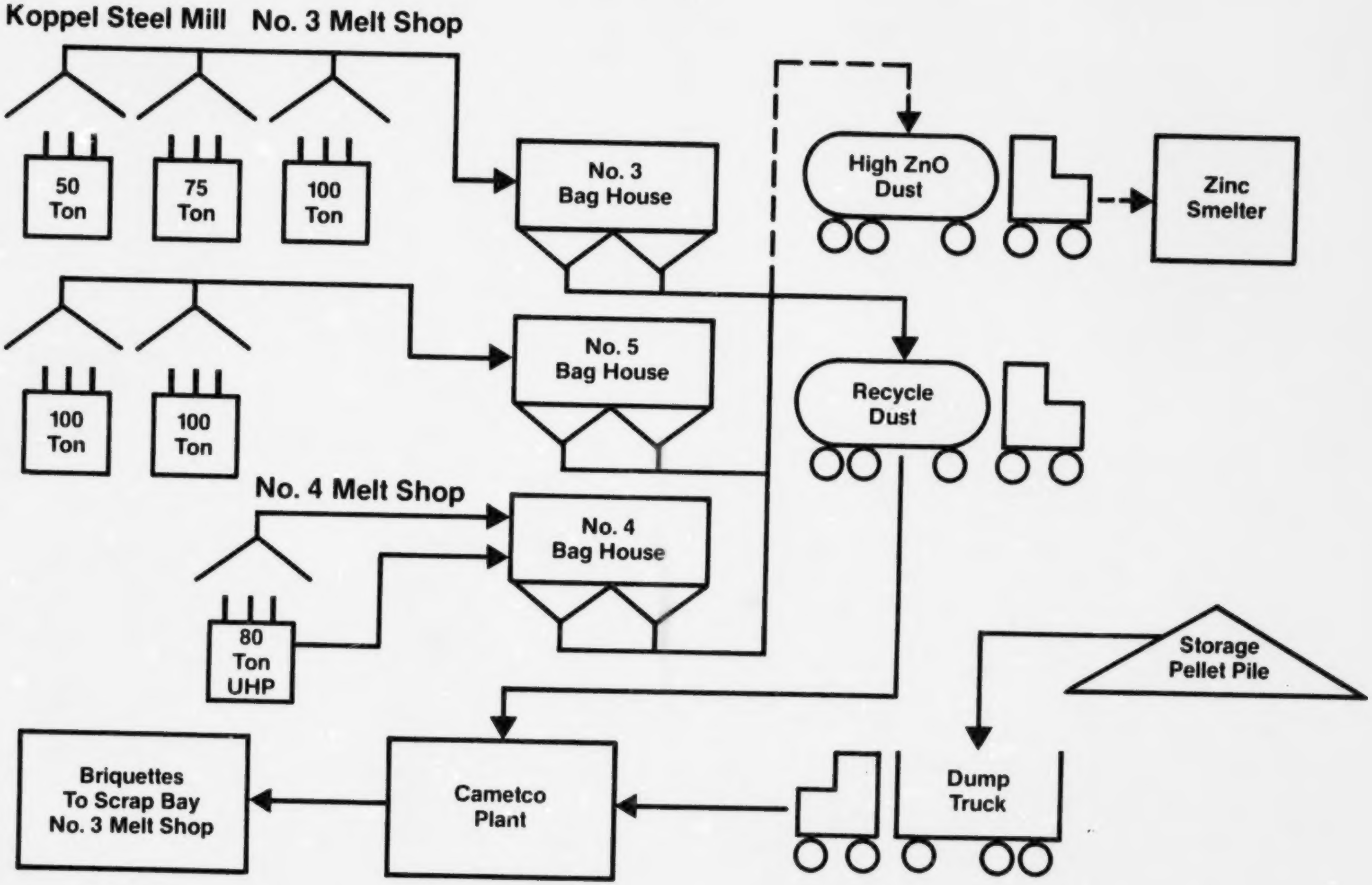
Koppel Steel Mill No. 3 Melt Shop
50 Ton
75 Ton
100 Ton
100 Ton
100 Ton
No. 4 Melt Shop
80 Ton UHP
No. 3 Bag House
No. 5 Bag House
No. 4 Bag House
High ZnO Dust
Zinc Smelter
Recycle Dust
Storage Pellet Pile
Dump Truck
Cametco Plant
Briquettes To Scrap Bay No. 3 Melt Shop

FIGURE 6

LABORATORY EVALUATION OF STEEL PRODUCTION WASTE STABILIZERS

by

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Since the information in this document has not been funded, wholly or in part, by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's peer and administrative review. Therefore, it does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

ABSTRACT

The ever-increasing public awareness of waste disposal as an environmental issue, along with the impact of regulatory overview, necessitates continual reappraisal of disposal practices. Such a consideration formed the basis for a recently completed laboratory study to evaluate the performance of several possible stabilizers for a mixture of electric furnace dust and sludge and pickle liquor sludge wastes currently disposed by landfilling. The paper discusses the formulation, implementation, and results of the study.

The objectives of the test program were twofold: (1) to provide geotechnical and geochemical behavioral data and (2) to evaluate the feasibility of blending various additives with the wastes to lower permeability, improve attenuation characteristics, and/or improve material handling. The laboratory program used a phased approach; Phase I consisted of relatively simple geotechnical tests (i.e., index, compaction, and strength tests) to assess general material behavior and thereby isolate combinations of waste, additive, and moisture content

showing the most promise for meeting the objectives. The Phase II program was used to characterize the hydraulic behavior and geochemical composition of leachates emanating from samples during permeability testing. The additives evaluated consisted of 4 percent bentonite, 5 percent cement, and 10 percent fly ash. Samples without additives were also tested for baseline control and comparison with undisturbed samples collected from the landfill.

Of the additives tested, only bentonite provided any substantive reduction in permeability (by a factor of two) while all of the additives increased the optimum moisture content of the waste mix which would result in improved handling characteristics during placement in the landfill. The leachate quality from all samples (including those without additives) was below U.S. Environmental Protection Agency (EPA) extraction procedure (EP) toxicity standards.

LANDFILL

The wastes are presently disposed at a 3.4-acre engineered landfill confined within a steeply sloped valley near Aliquippa, Pennsylvania. The primary landfill components consist of a drainage blanket and compacted liner over the original steeply sloped surface, a stabilizing buttress at the toe of the waste embankment, a leachate collection system extending to a sump where leachate can be collected and treated, and perimeter surface and subsurface water monitoring stations. The drainage blanket and liner were constructed using a three-foot-thick layer of iron blast furnace slag and 1-1/2-foot-thick mixture of fly ash and steel-making slag, respectively. The leachate collection system consists of a two-foot-thick layer of steel-making slag above the liner and a six-inch-diameter perforated leachate collection pipe located behind the buttress at the toe of the embankment.

The wastes, which are trucked to the landfill, consist of bag house and electric furnace precipitator (EFP) dusts, EFP sludge, and a stainless steel lime neutralized waste pickle liquor sludge (PLS). The EFP dust is mixed with the EFP sludge prior to transport. The EFP mixture has a large variation in moisture content depending on the degree to which the sludge is dewatered. The PLS has a high moisture content of approximately 150 percent. The wastes are mixed and placed at the landfill using dozers and the working surface is continually graded to impound precipitation for pumping and disposal as needed. Since the landfill was opened in 1981, no measurable quantity of leachate has been collected.

PURPOSE OF STUDY

Due to the potentially wide variation in the moisture content and material composition of the mixed wastes, problems developed during landfilling relative to blending and placing of wastes. Further, because the wastes have been listed as hazardous by the EPA and the Pennsylvania Department of Environmental Resources, there was interest in compiling geotechnical and geochemical data to ascertain the rate and composition of leachates emanating from the wastes. A laboratory testing program was undertaken with the following objectives:

- Evaluate the feasibility of blending various additives with the waste(s) to either lower the permeability to values comparable with compacted fine-grained soils and/or alter the compaction characteristics of the waste(s) to reduce current problems with waste placement.

- Provide geotechnical and geochemical data on the behavior of the waste(s) and wastes plus additives.

LABORATORY TEST PROGRAM

The laboratory program was developed using a two-phase approach. The Phase I program consisted of relatively simple geotechnical tests to assess general material behavior and thereby isolate those combinations of waste, additive, and moisture content showing the most promise for meeting the project objectives. The Phase II program was used to (1) characterize the hydraulic behavior of compacted samples by performing permeability tests, and (2) characterize the geochemical behavior of permeated effluents by analyzing fluid collected periodically throughout the permeability testing.

The composition of the waste materials tested consisted of the following:

- A laboratory-prepared mixture of 1.3 parts (dry-weight basis) EFP sludge, 5.2 parts EFP dust, and 3.5 parts (dry-weight basis) PLS (Mix 1)
- A laboratory-prepared sample of EFP dust
- An undisturbed sample of waste from LTV's Aliquippa landfill collected approximately 6 to 12 months after placement.

The additives considered in the study included bentonite (Bariod National Standard), fly ash (from previous steel production waste studies by IT Corporation), and cement (Type I). These additives and their quantities were selected because they had been used or tested previously by LTV (i.e., fly ash and cement), because they represented a potentially economic stabilizer, or because they could improve compaction and/or reduce permeability (i.e., bentonite).

Phase I

The test matrix used for the Phase I program is summarized in Table 1. Most of the testing utilized a blended mix of waste materials (Mix 1) which is considered to be representative of an average mix of wastes disposed at the landfill. The effect of additives on Mix 1 behavior was evaluated by introducing bentonite (Mix 2), fly ash (Mix 3), and cement (Mix 4) in the proportions shown in Table 1. In addition to these mixes, the behavior of the EFP dust with bentonite was also studied (Mix 5).

The Phase I program consisted of a combination of simple geotechnical laboratory tests to establish index and mechanical properties. As shown in Table 1, the scheduled index tests included particle size, Atterberg limits, and specific gravity to define the grain distribution, plasticity, and grain density of the materials tested. The moisture content of the as-received wastes was also determined. These tests were conducted in accordance with the most recent ASTM Standards[1]. Compaction tests were performed to evaluate the effect of moisture content on the compaction behavior of each mix. To minimize the quantity of materials to be tested, a modified compaction test procedure was developed utilizing an inexpensive plastic mold with the approximate dimensions of two inches in diameter by four inches high. Although a nonstandard procedure was used, a compactive effort was established to provide a unit weight comparison with the Standard Test Method[1]. The effects of stabilization (e.g., hydration) were evaluated by curing the samples which had been compacted in the plastic molds. These effects were monitored using pocket penetrometer and moisture content determinations to measure changes in sample strength and moisture content at various time intervals over a 28-day period. The possible development of shrinkage cracks due to drying was also evaluated by placing the mold and sample remaining after 28 days in a drying oven and visually examining the dried samples for cracks.

Phase II

The Phase II program consisted of a series of column/leachate permeability tests using those combinations of waste or waste plus additive from the Phase I study which showed the most positive results. Table 1 shows that the Phase II test matrix included all mixes studied during Phase I, except the fly ash mixture, in addition to an undisturbed field sample acquired from the landfill. Fly ash was eliminated from consideration primarily because of the cost associated with trucking this stabilizer to the landfill. The tests included permeability measurement, analysis of effluent chemistry, and strength testing using a pocket penetrometer. Laboratory-prepared samples for permeability testing were compacted at a moisture content approximately 5 to 8 percent wet of optimum and, with the exception of one sample, each was permeated immediately following compaction. The sample which was not tested immediately after compaction was cured for 14 days prior to permeation to determine the effect of curing on the permeability and effluent chemistry for Mix 1. These permeability samples were compacted wet of optimum to represent a compromise between the optimum compaction conditions (average optimum moisture content of Mix 1 of about 35 percent) and the actual conditions existing in the field (about 50 percent) during placement. The undisturbed sample was tested to provide reference data to the laboratory-prepared specimens. The effluents leached from the permeability test samples were tested for pH, specific conductance, cadmium, chromium, lead, and nickel[2]. The metals were selected based on previously conducted EP toxicity test[3] results.

DISCUSSION OF RESULTS

Phase I

The grain density or specific gravity of the wastes before mixing was measured in accordance with ASTM D 854. Natural moisture contents were also determined for the as-received wastes in accordance with ASTM D 2216. These results are listed below:

SAMPLE	SPECIFIC GRAVITY	NATURAL MOISTURE CONTENT (%)
EFP Sludge	4.56	50
EFP Dust	4.86	0.6
PLS	3.03	131
Mix 1	4.17 (calculated)	51 (calculated)

The specific gravity values are higher than most soils (i.e., $G_s = 2.65$ to 2.75) and reflect the higher grain density of constituents in the steel production wastes. Grain size distribution tests (ASTM D 422) were performed using the hydrometer method, but they could not be analyzed due to the wide variation in the specific gravity of the individual components (EFP dust, EFP sludge, and PLS) of the mixes. The plasticity characteristics (Atterberg limits) of selected samples were determined in accordance with ASTM D 423 and all of the mixes were found to have low plasticity (i.e., approximately 10).

Moisture-density relationships were determined for Mixes 1 through 5 (Table 1) using a compaction hammer (2-pound weight, 7-inch drop, 1.5-inch-diameter impact face) and mold (approximately 1.6 inches in diameter, 4 inches long) which are smaller than those specified in the standard method (ASTM D 698). To relate the results obtained using the smaller apparatus to the standard test method, tests were performed on Mix 1 at a water content of 15 percent using both methods. The compactive effort (i.e., number of tamps per layer) of the smaller apparatus was adjusted until the resulting dry unit weight was within ±2 percent of that obtained using the standard procedure. The smaller apparatus required five layers with 80 blows per layer to achieve equivalent results. The results of the compaction tests are presented in Figure 1. The maximum dry unit weight, γ_d, and optimum moisture content, w_{opt}, for each mix is also shown in the figure. For reference, the figure also includes the results of a standard compaction test and field density measurements measured at the landfill. The moisture-density relationship for Mix 1 is located above and to the left of those for Mixes 2, 3, and 4 which results from the inclusion of additives having specific gravities which lower the overall unit weight of Mix 1. Similarly, the moisture-density curve for Mix 5 is located above the Mix 1 curve due to the higher specific gravity of the EFP dust relative to Mix 1. Figure 1 also shows that the laboratory tests are consistent with the field test results provided by LTV. The range of results probably can be attributed to variations in the composition of the landfilled wastes relative to Mix 1.

Each moisture-density sample was compacted in a separate plastic mold so the rate of strength change with time after compaction could be periodically monitored using a pocket penetrometer. Immediately after compaction, each sample was tested using a pocket penetrometer, sampled for moisture content, and placed in a sealed plastic bag for curing. Periodically, each sample mold was removed from its bag, and pocket penetrometer and moisture content determinations were made. Selected test results are presented in Table 2. Only the samples having a moisture content ranging between 1 to 9 percent wet of optimum showed any measurable increase in pocket penetrometer resistance with time. Samples compacted dry of optimum (not presented in Table 2) showed a pocket penetrometer resistance greater than 4.5 tons per square foot (TSF), which indicates the material can be readily compacted in the field and support construction equipment. Conversely, samples wetter than 1 to 9 percent of optimum moisture content showed virtually no strength and only little strength improvement with time. This provides some insight to the construction difficulties observed at the landfill when the sludge wastes have high moisture contents. No trends in the change of moisture content with time (i.e., increase or decrease) could be discerned over the 28-day test period.

It is also noteworthy that the undisturbed landfill sample naturally aged in the field had a strength equal to or greater than the best performance of laboratory prepared samples.

To assess the potential for the samples to crack upon drying, the mold and sample retained in each mold at the end of penetration testing was oven dried. Visual examination of each sample showed no or very limited tendency for cracking.

The Phase II study consisted of a series of permeability tests, including effluent chemical analysis, to determine the hydraulic flow and geochemical characteristics of the samples and effluents.

The permeability samples were prepared by mixing predetermined dried proportions of each admixture, adding tap water to about 5 to 8 percent wet of the optimum moisture content, and compacting the blended mixture in a 2.8-inch-diameter mold to approximately 95 percent of the maximum dry unit weight. The compacted samples were enclosed between end platens and a latex membrane and then placed in a triaxial pressure chamber. An all-around fluid pressure was applied to the system to prevent channel flow between the sample and the membrane, then a back pressure was applied to the sample to saturate the sample and test system. The samples were permeated with a standard 0.01 N calcium sulfate solution[4] using the apparatus illustrated in Figure 2 in accordance with Haji-Djafari and Wright[5]. A pressure gradient of approximately 25 was used to drive the fluid through the samples. Effluent samples were collected for atomic absorption spectrophotometry analysis[2] at approximately each pore volume of flow until a minimum of six pore volumes of fluid had been exchanged.

The steady-state coefficient of permeability for each tested sample is summarized below:

TEST SAMPLE	PERMEABILITY (cm/sec)(*)
Mix 1 (fresh)	4×10^{-7}
Mix 1 (14 days curing)	5×10^{-7}
Undisturbed landfill (field) sample	5×10^{-7}
Mix 2 (Mix 1 + 4 percent bentonite)	2×10^{-7}
Mix 4 (Mix 1 + 5 percent cement)	5×10^{-7}
Mix 5 (EFP dust + 4 percent bentonite)	3×10^{-7}

(*) cm/sec = Centimeters per second, adjusted to 20° Centigrade.

Mix 1 is the laboratory mix prepared to represent field conditions. As shown above, both tests conducted using Mix 1 compare very well with the results obtained using an undisturbed sample acquired from the landfill. Likewise, no significant differences were observed between the Mix 1 permeability test results and the other mixtures tested. Therefore, based on permeability alone, little benefit can be derived by adding the stabilizers to the combination of wastes disposed at the landfill.

Pertinent results from the effluent monitoring program are presented in Figure 3. The effluent monitoring shows that the concentrations for those parameters monitored generally decrease with time. The field block sample from the Aliquippa landfill (which is believed to have been placed approximately 6 to 12 months prior to sampling) showed the best overall leachate quality, with the exception of its alkaline pH (approximately 11.5), which may be the result of leaching in the field prior to laboratory testing. Mix 4 similarly showed leachate pH values in excess of pH 11, which is believed to be due to the presence of unhydrated cement. Either or both samples may have contained an excess of free lime. Leachate pHs were alkaline for all six mixes, ranging between 7.0 and 11.6.

The lowest effluent specific conductance (an electrical measurement of dissolved solids) is associated with the very alkaline leachates, i.e., Mix 4 and the field sample. This is most likely the result of lower mineral (metal precipitates) solubilities at higher pHs. Mix 5, the EFP dust mix, had the highest effluent specific conductances, with an initial specific conductance of 31,100 μmhos/cm. Mixes 1 (after curing) and 2 also had leachate specific conductances greater than 10,000 mhos/cm.

Concentrations of the four metals monitored in the column effluents were below EPA EP toxicity levels. As with specific conductance and, to some extent, pH, metal levels generally decreased with continued leaching. The metal concentration decreases do not appear to be pH-related as shown in Figure 3. Lead and cadmium were generally below detection levels in all of the samples. Nickel did not exceed 0.5 milligram per liter (mpl) in any sample and generally reached an equilibrium concentration of approximately 0.1 ppm with continued leaching. The maximum chromium concentration measured was approximately 3.0 ppm. Chromium generally decreased to less than 1.0 ppm with continued leaching. The measured chromium concentration from the field sample was less than 0.1 ppm.

CONCLUSIONS

The test results indicate that, with respect to the field sample and/or Mix 1, there is little to be gained by either curing a mix prior to field placement, adding 4 percent bentonite, or adding 5 percent cement. In general, the effluent monitoring for the permeability tests shows that the concentrations for the parameters monitored decreased as the leachate quality improved with time. As expected, a slight decrease in permeability (factor of about two) and a sizeable increase in undrained shear strength (measured by pocket penetrometer) can be realized with the addition of 4 percent bentonite. The addition of 5 percent cement resulted in no measurable change in permeability, but did result in a significant increase in undrained shear strength. It should also be noted that the addition of 4 percent bentonite to the EFP dust sample resulted in a material slightly less permeable than Mix 1. The EFP dust plus bentonite mixture also has the highest undrained shear strength and highest dry density due partly to its high specific gravity. These results represent the conditions for moisture contents ranging from 1 to 9 percent wet of optimum moisture content.

The test results indicate that the landfill disposal operations have little to gain by adding the types and amounts of the additives studied in this program.

The observed materials handling difficulties at the landfill can be reduced by drying (by blending or otherwise) the waste mixture(s) closer to its optimum moisture content. Drying will better utilize the wastes' inherent properties and additives can be introduced if necessary to improve the strength and/or permeability to desired or acceptable values.

REFERENCES

(1) American Society for Testing and Materials (ASTM), Annual Book of Standards, Volume 04.08, Natural Building Stones; Soil and Rock, ASTM, Philadelphia, Pennsylvania. In all cases, the most recent standards available at the time of testing were used.

(2) U.S. Environmental Protection Agency, Technology Transfer, 1979, "Methods for Chemical Analysis of Water and Wastes," EPA-600/4-79-020, U.S. Environmental Protection Agency, Washington, D.C.

(3) U.S. Environmental Protection Agency, 1980a, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," SW-846, Office of Water and Waste Management, U.S. Environmental Protection Agency, Washington, D.C.

(4) U.S. Environmental Protection Agency, 1980b, "Test Method for the Permeability of Compacted Clay Soils (Constant Elevated Pressure Method), in Lining of Waste Impoundments and Disposal Facilities," SW-870, Appendix III, Office of Water and Waste Management, U.S. Environmental Protection Agency, Washington, D.C., pp. 264-269.

(5) Haji-Djafari, S., and J. C. Wright, Jr., 1983, "Determining the Long-Term Effects of Interactions Between Waste Permeants and Porous Media," Hazardous and Industrial Solid Waste Testing: Second Symposium, ASTM STP 805, R. A. Conway and W. P. Gulledge, eds., American Society for Testing and Materials, pp. 246-264.

Table 1, TEST MATRIX.

		PHASE I					PHASE II				
							PERMEABILITY TESTING				
MIX NUMBER	MIX INGREDIENTS	PARTICLE SIZE DISTRIBUTION[1]	ATTERBERG LIMITS	COMPACTION TEST	POCKET PENETROMETER	SPECIFIC GRAVITY	FRESH LAB COMPACTED SAMPLE	AGED LAB COMPACTED SAMPLE	AGED FIELD COMPACTED SAMPLE	EFFLUENT CHEMISTRY[4]	POCKET PENETROMETER
NA	EFP Sludge	-	-	-	-	●	-	-	-	-	-
NA	EFP Dust	-	●	-	-	●	-	-	-	-	-
NA	PLS	-	-	-	-	●	-	-	-	-	-
1	1.3 parts EFP[2] sludge 5.2 parts EFP dust 3.5 parts PLS[3]	●	●	●	●	●	●	●	-	●	●
2	Mix 1 plus 4 percent bentonite by dry weight	-	●	●	●	-	●	-	-	●	●
3	Mix 1 plus 10 percent fly ash by dry weight	-	●	●	●	-	-	-	-	-	-
4	Mix 1 plus 5 percent cement by dry weight	-	●	●	●	-	●	-	-	●	●
5	EFP dust plus 4 percent bentonite by dry weight	●	●	●	●	-	-	-	-	●	●
6	Undisturbed sample from Aliquippa landfill	-	-	-	-	-	-	-	●	●	●

● = Test scheduled.

- = No test scheduled.

[1] Grain size distribution tests were scheduled but could not be analyzed due to the different specific gravities of the individual components of each mixture. A hydrometer test assumes all particles have the same specific gravity.

[2] Electric furnace precipitator.

[3] Pickle liquor sludge.

[4] Includes pH, specific conductance, and atomic absorption spectrophotometry analyses for Pb, Cd, Ni, and Cr cations at a minimum of 6 one pore volume intervals.

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Table 2, SELECTED SUMMARY OF TIME EFFECTS ON SAMPLE BEHAVIOR.(1)

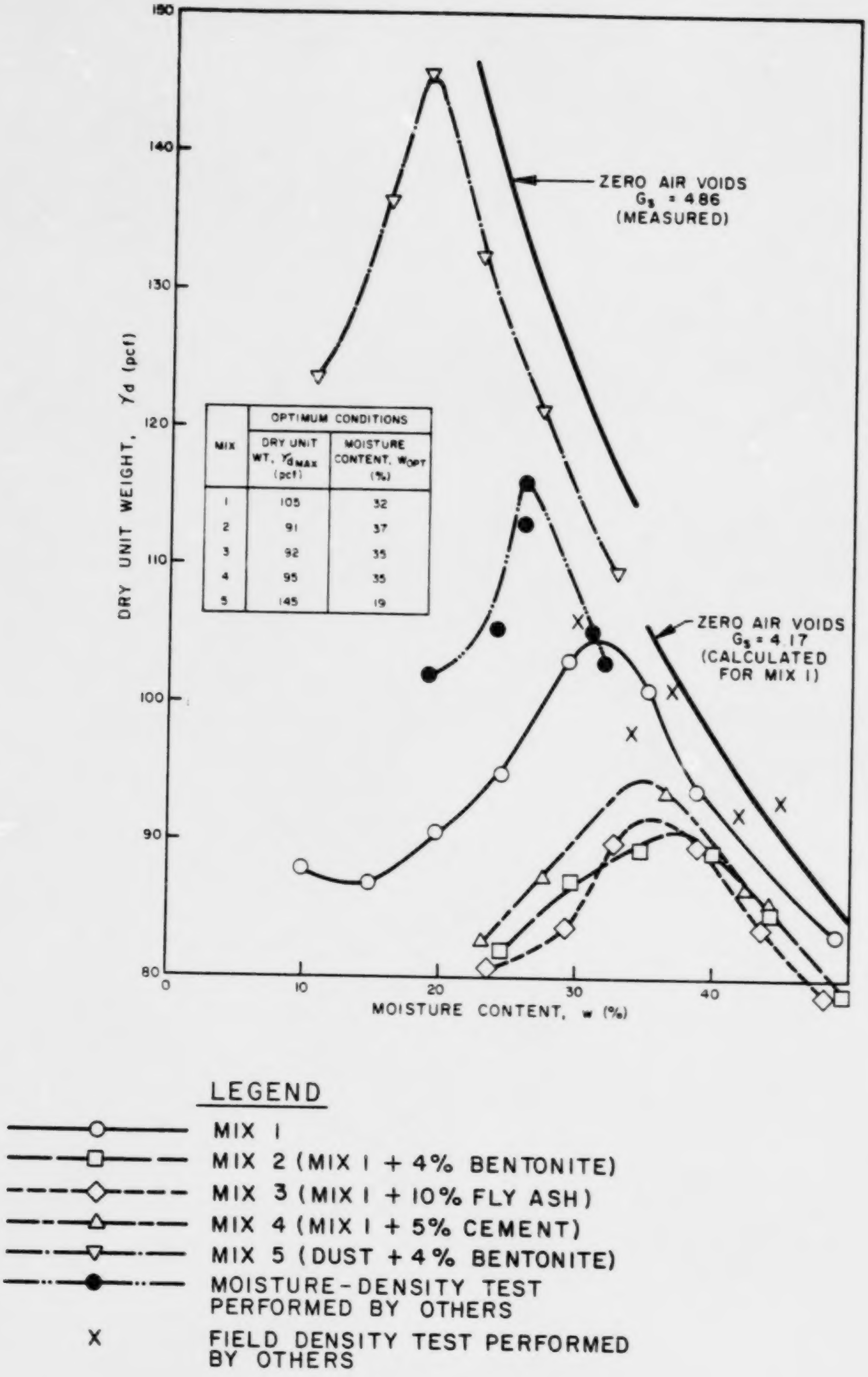
MIX NO.	w_{avg}(2) (%)	w_{opt}(3) (%)	POCKET PENETROMETER (TSF)(4)					
			0 DAY	1 DAY	3 DAYS	7 DAYS	14 DAYS	28 DAYS
1	34	32	2.2	3.0	2.5	3.5	4.2	>4.5
2	38	37	2.5	2.2	2.2	2.8	3.5	>4.5
3	37	35	2.2	2.2	2.2	2.8	3.5	>4.5
4	41	35	0.8	0.8	1.0	1.5	2.0	3.0
5	23	19	1.8	1.5	1.5	2.3	2.7	4.5
5	28	19	0.2	0.2	0.2	0.5	0.8	1.0

(1) Those samples tested which were drier than the average moisture content listed had pocket penetrometer test results greater than 4.5 tons per square foot.

(2) Average moisture content.

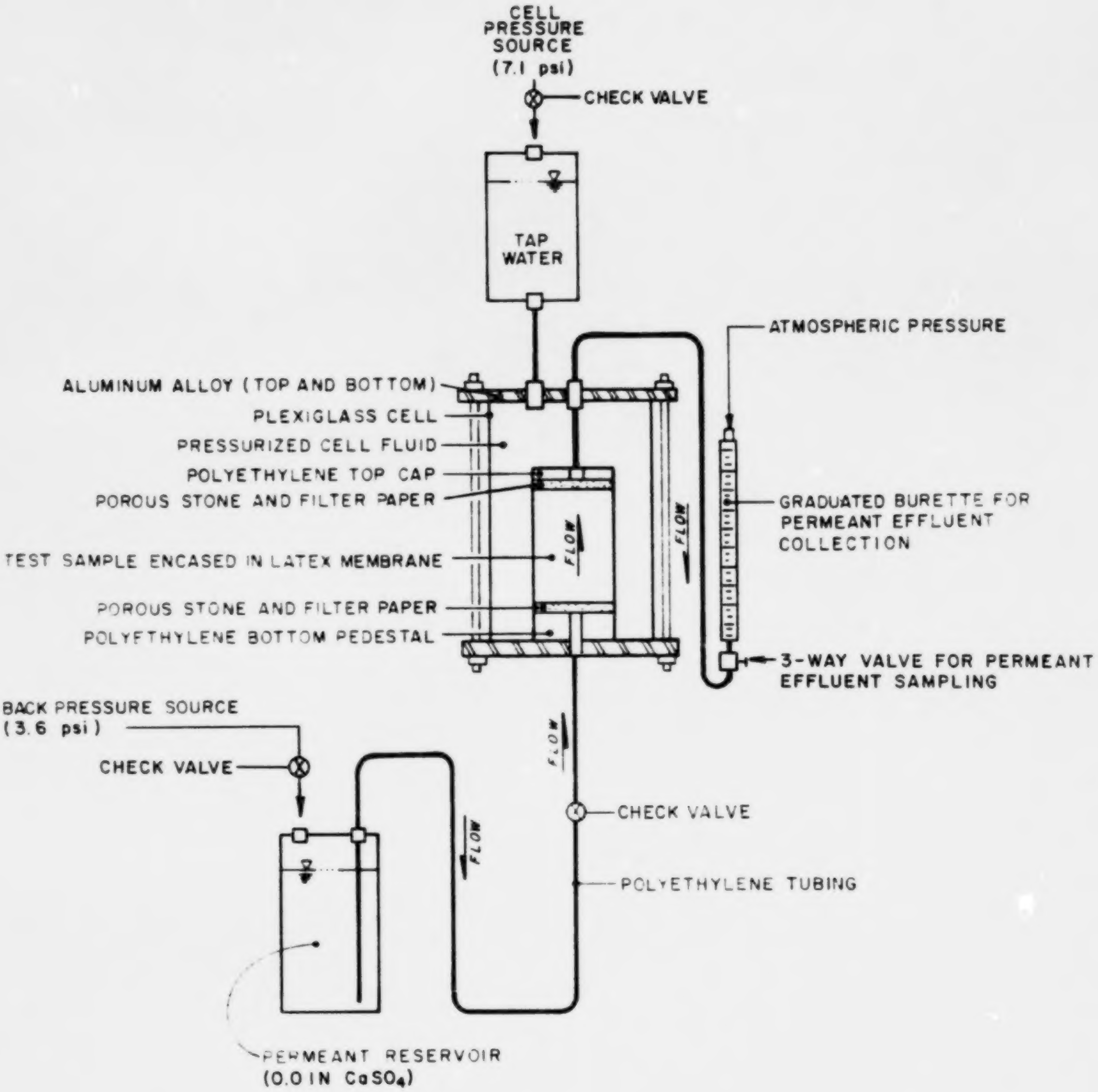
(3) Optimum moisture content.

(4) Undrained shear strength in tons per square foot.



MIX	OPTIMUM CONDITIONS	
	DRY UNIT WT, $\gamma_{d_{MAX}}$ (pcf)	MOISTURE CONTENT, w_{OPT} (%)
1	105	32
2	91	37
3	92	35
4	95	35
5	145	19

Figure 1, MOISTURE – DENSITY RELATIONSHIP.


CELL PRESSURE SOURCE (7.1 psi)
CHECK VALVE
TAP WATER
ATMOSPHERIC PRESSURE
ALUMINUM ALLOY (TOP AND BOTTOM)
PLEXIGLASS CELL
PRESSURIZED CELL FLUID
POLYETHYLENE TOP CAP
POROUS STONE AND FILTER PAPER
GRADUATED BURETTE FOR PERMEANT EFFLUENT COLLECTION
TEST SAMPLE ENCASED IN LATEX MEMBRANE
FLOW
FLOW
POROUS STONE AND FILTER PAPER
POLYETHYLENE BOTTOM PEDESTAL
3-WAY VALVE FOR PERMEANT EFFLUENT SAMPLING
BACK PRESSURE SOURCE (3.6 psi)
CHECK VALVE
FLOW
CHECK VALVE
FLOW
POLYETHYLENE TUBING
PERMEANT RESERVOIR (0.01N $CaSO_4$)

NOTE:

ALL FITTINGS IN CONTACT WITH PERMEANT ARE POLYETHYLENE.

Figure 2, SCHEMATIC OF LONG-TERM TESTING SYSTEM (ONE SAMPLE SHOWN).

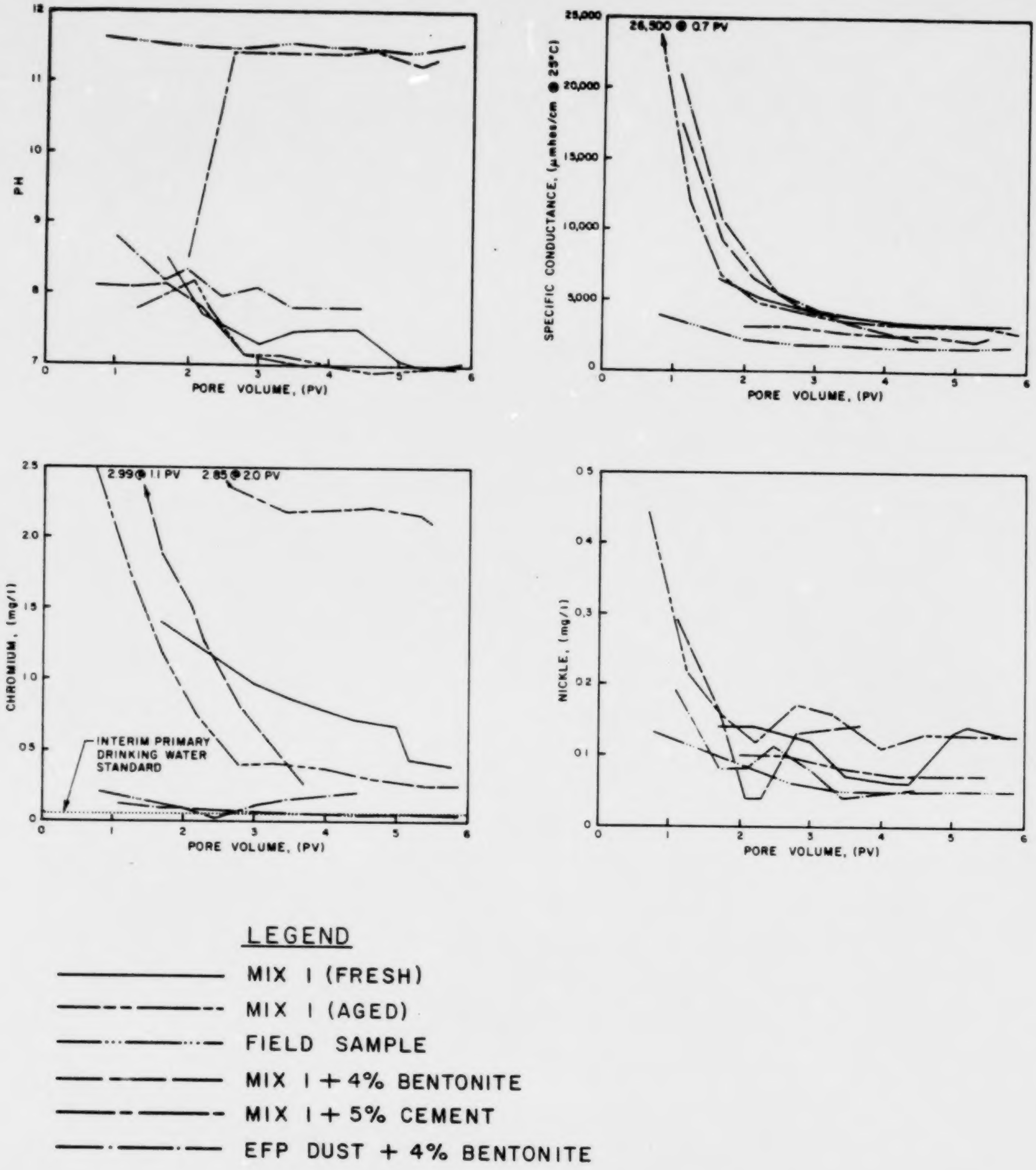


Figure 3, EFFLUENT MONITORING RESULTS.

UPGRADING A PRIMARY SEWAGE TREATMENT PLANT BY USING SPENT PICKLE LIQUOR AS A COAGULANT

by

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ABSTRACT

As part of the long-range plan to upgrade the Municipality of Metropolitan Seattle's (Metro's) Alki primary wastewater treatment system, spent pickle liquor from Bethlehem Steel's local industrial fastener plant will be used as a coagulant. This is a new and innovative use for spent pickle liquor from steelmaking operations; upgrading a primary plant by enhancing the removal of raw sewage solids.

The Alki Plant handles about 6 million gallons per day of raw sewage from a population of about 50,000. Presently the facility removes only 45% of the BOD_5 (5-day biochemical oxygen demand) and 70% of the total suspended solids entering the plant. Results of a cooperative test program between Bethlehem and Metro demonstrated that spent sulfuric acid pickle liquor from batch pickling operations can be used as an efficient and cost-effective coagulation chemical to improve BOD_5 and the removal of sewage solids.

In order to be effective, however, the ferrous iron in the pickle liquor must be converted to ferric iron ahead of the existing sedimentation tanks. This is accomplished by adding 0.5 lbs of chlorine in a water solution per lb of added ferrous iron. This diluted pickle liquor chlorine mixture is then injected into the sewage where the ferrous-ferric conversion occurs allowing the flocculated iron precipitate to be formed. This precipitate is then removed along with the flocculated sewage solids in the solids-liquid separation portion of the facility.

This technology will allow Metro to upgrade its primary plant without major capital or operating expenses. As a result, Metro has proceeded with engineering a permanent pickle liquor/chlorine storage and injection facility upstream of the grit chambers and sedimentation tanks.

(NOTE: This paper was not presented at the symposium, despite being scheduled.)

EXTRACTION OF OIL FROM MILL-SCALE

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ABSTRACT

Pilot plant and laboratory studies have demonstrated that oil can be successfully extracted from a variety of steel mill and metalworking wastes using liquefied gas extractions. The extraction of mill scale is an example of a stream which has been successfully extracted. The preliminary design and costs of a 90,000 ton/year mill-scale extraction plant have been completed. The results show the process is technically viable and economically attractive.

The pilot-plant data on the liquefied gas extraction of oil from mill scale includes analyses of both the de-oiled mill scale and the extracted oils, as well as operating conditions and process dependence on various parameters. The oil analyses indicate it is suitable for use as fuel, while the mill scale quality allows it to be recycled to a sinter plant. The payback period for a process based on the experimental results is 15 months.

Since the information in this document has not been funded, wholly or in part, by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's peer and administrative review. Therefore, it does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

EXTRACTION OF OIL FROM MILL SCALE

SUMMARY

Critical Fluid Systems, Inc., (CFS), a subsidiary of Arthur D. Little, Inc., has developed several extraction processes based on the use of liquefied gases and supercritical fluids. Among these processes is a method for de-oiling steel mill wastes such as mill scale using liquefied gases as extraction solvents at pressures of about 700 kPa (100 psi) and ambient temperature. This process offers several advantages over conventional de-oiling techniques. Among the advantages are:

1. Simple equipment
2. Low capital costs
3. Low operating costs, primarily as reduced energy consumption
4. Recovery of both oil and mill scale
5. Low solvent losses
6. No waste stream

A variety of steel mill scales have been de-oiled by extraction in CFS's Cambridge, Massachusetts pilot plant facility in an EPA-funded project. Data from these experiments as well as projected capital and operating costs of a 90,000 ton per year mill scale de-oiling plant indicate a process which is both technically feasible and economically attractive.

Mill scale ranges from 1.5 to 10% of total raw steel production. It is one of a number of oily steel mill effluents (summarized in Table 1) and is a prime candidate for de-oiling. Already up to one-half of these scales are recycled to the blast furnace, usually by way of a sintering operation. The sintering plant is, however, adversely effected by oils. By de-oiling the mill scale, this waste by-product can be recycled into product.

Several de-oiling methods have been tested by others. Water washing with hot alkaline solution can remove, at best, 90-95% of the oil on mill scale fines at low cost; however, although the oily solids problem is eliminated, it is replaced with an oily water problem. The mill scale can be charged to a thermal incinerator, but the cost of off-gas treatment (by after-burning or scrubbing) can quickly offset the economic advantages of raw material recycling. A direct-fire kiln of this type has been reported in commercial use. Conventional solvent washing has also been considered. While solvent washing

TABLE 1

IRON-CONTAINING SOLID WASTES GENERATED IN STEEL MILLS

	Hydrocarbon Content (%)	Iron Content (%)	Water Content (%)	Contaminants	Tonnage* (TPY)
Sinter Plant Scrubber Sludge	0-2	20-40	2-40	Alkalies, Zn, Pb	400-500
Mill Scale	0.01-15	60-75	2-5	---	37,500-250,000
Scarfer Scale	0.01-0.5	70-85	5-10	---	30,000-60,000
Hot Rolling Mill Sludges	5-30	60-70	21-58	---	2,000-4,000
Cold Mill Sludges	2-7	---	81-88	Zn, Sn	5,000-7,000
Centerless Grindings	---	60-85	---	---	2,500
Waste Water Treatment Sludges	2-8	0-44	40-78	P, Zn, Cr, Sn	7,000-20,000
Creek Dredge Spoil	Neg.-2	Neg.-40	30-50	SiO_2, Al_2O_3, S	Neg.-5,000

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*Based on a nominal 2.5 MTPY steel plant.

offers the prospect of oil recovery and acceptable levels of mill scale de-oiling, the energy costs associated with solvent recovery from oil and mill scale, as well as the cost of make-up solvent, may again offset the value of the recovered material.

Critical fluid extraction yields both oil and de-oiled mill scale products with the added benefit of lower cost solvent recovery and simple solid de-solventizing over the washing process or extraction utilizing conventional solvents. It may also offer considerable reduction in energy consumption and operating costs over conventional processes.

An economic analysis of a critical fluid extraction process demonstrates that the scheme is not only feasible but, with its rapid payback, attractive.

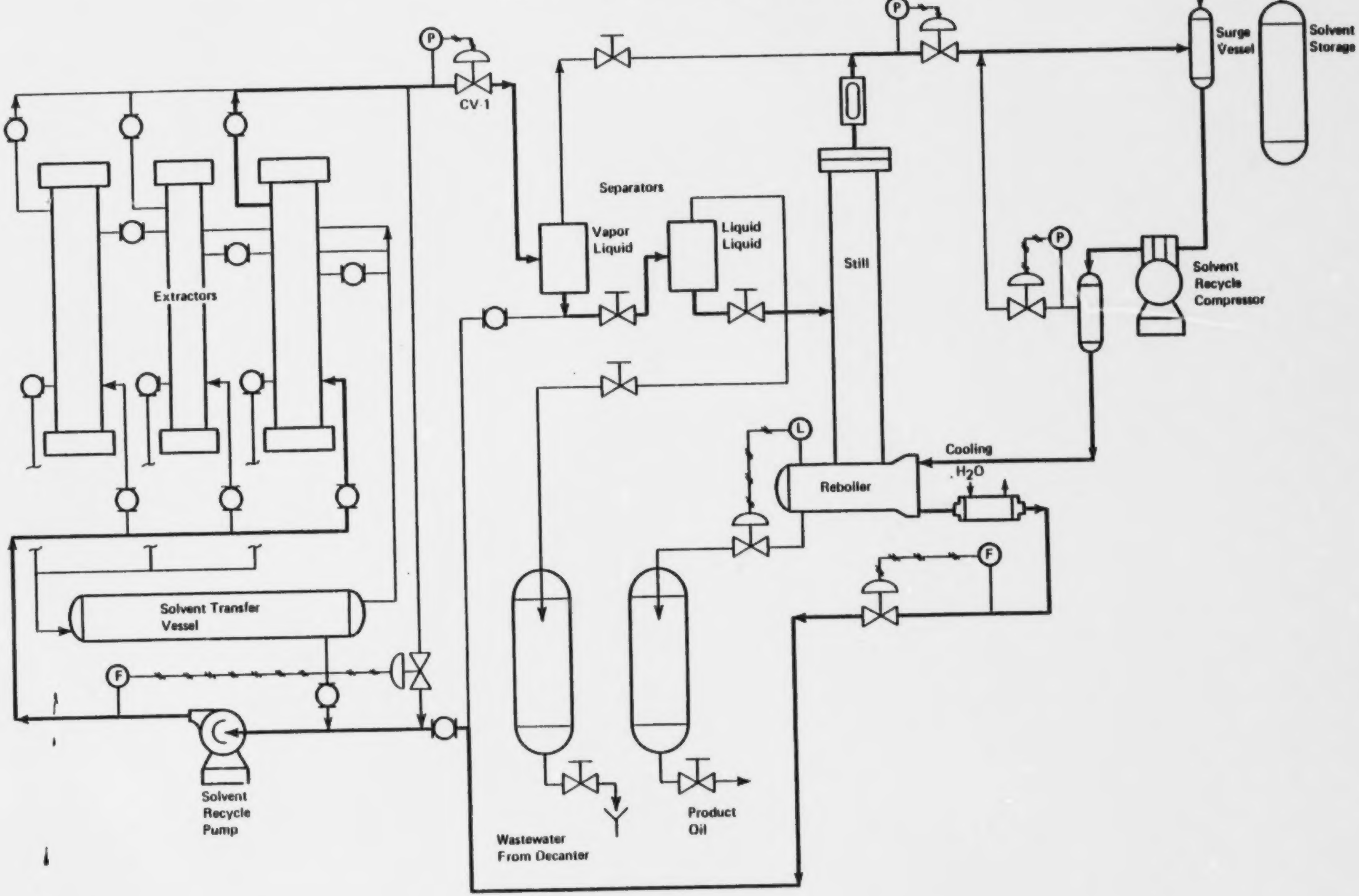
CRITICAL FLUID SYSTEMS MILL SCALE PROCESS

A "critical fluid" is a fluid near its thermodynamic critical temperature and pressure. At the critical point there is no distinct liquid or vapor state. The various properties (e.g., density, viscosity, and diffusivity) of the fluid in the supercritical state - temperature and pressure just above the critical point - are intermediate between the corresponding values of the fluid in the gas and liquid states. Further, these properties as well as solvent properties are not fixed. They can be varied by manipulating temperatures and/or pressures, thus presenting new avenues for extractions and separations. Further, a critical fluid solvent is easily separable from the extracted residues and products, thus cutting solvent recovery costs.

Many separation processes do not require the subtleties of operating at the critical point, but can use a liquefied gas with many of the advantages of a supercritical fluid and at substantially lower pressures. Such a process is that employed by CFS for the de-oiling of mill scale. Thus, conventional solvent extraction techniques can be coupled with critical fluid solvent recovery techniques by using condensed gas solvents.

A process flow diagram for our pilot plant is shown in Figure 1. The liquefied gas solvent flows continuously to the batch solids extractor during extraction. Here the solvent extracts oil as it passes through the mill scale bed. As the solvent-oil solution leaves the extractor through a back pressure regulator its pressure is lowered. The solvent-oil mixture then goes to the still where the solvent is vaporized and sent to the compressor. The product oil is concentrated in the still bottom and is sent to a product receiver as required to maintain the desired liquid level and composition in the still bottom.

FIGURE 1 MILL SCALE PILOT PLANT FLOW DIAGRAM



Surge Vessel
Solvent Storage
P
CV-1
Separators
Vapor Liquid
Liquid Liquid
Still
P
Solvent Recycle Compressor
Extractors
L
Cooling H2O
Reboiler
F
Solvent Transfer Vessel
F
Solvent Recycle Pump
Wastewater From Decanter
Product Oil

Solvent vapor from the top of the still is compressed. This superheated, pressurized gas is cooled and liquefied in a vapor recompression cycle in the still reboiler before being returned to the extractor as a liquid.

EXPERIMENTAL STUDIES

A. Apparatus

Pilot scale experimental studies have been performed utilizing a plant based on the process diagram of Figure 1. The pilot extractors are 15 cm in diameter, 1.5 m long carbon steel columns equipped with multiple inlets and outlets. Each extractor has a capacity of about 35 kg of mill scale. The solvent connections on the extractors allow upflow, downflow, and crossflow extraction experiments. A back pressure control valve maintains extractor pressure, typically at 700 kPa (100 psi). The solvent-oil mixture passes through two phase separators to remove any vapor or water phase. The still is a 10 cm diameter by 1.5 m long tower coupled at its base to a 16 liter kettle-type reboiler containing 13 meters of 1.3 cm diameter coils in the reboiler (about 0.5 m^2 of heat transfer surface) to allow for efficient heat exchange between the reboiler contents and the compressor effluent. The still pressure is maintained at about 250 kPa (35 psi) less than the extractor pressure by another back pressure control valve. The compressor capacity is 85 lpm, (3 cfm) with a maximum discharge pressure of 1700 kPa (250 psi). Solvent flow to the extractor is controlled with a mass flowmeter, coupled to a controller and control valve. Some of the control, monitoring, and data logging functions are accomplished both manually and with a process computer.

B. Procedures

The extraction procedure starts by charging about 35 kg of mill scale into the extractor. The extractor is sealed and filled with liquid solvent under pressure. When the extractor is full of liquid, a continuous solvent flow is maintained through the extractor. Solvent leaving the extractor is periodically sampled and the oil content determined. The solvent-oil mixture is filtered, its pressure is reduced to still pressure, then it passes through two decenter/separator vessels to remove any vapor or aqueous phase prior to entering the still. The solvent and oil then go to the still, the solvent is continuously boiled off and the concentrated oil is periodically drained. At the end of the experiment the solvent is drained, the extractor de-pressurized, and the solids sampled and removed. The feed and the residue solids are analyzed for oil by soxhlet extraction, and the extraction efficiency calculated according to the following formula:

$$\frac{\text{oil extracted}}{\text{oil available}} = \text{extraction efficiency}$$

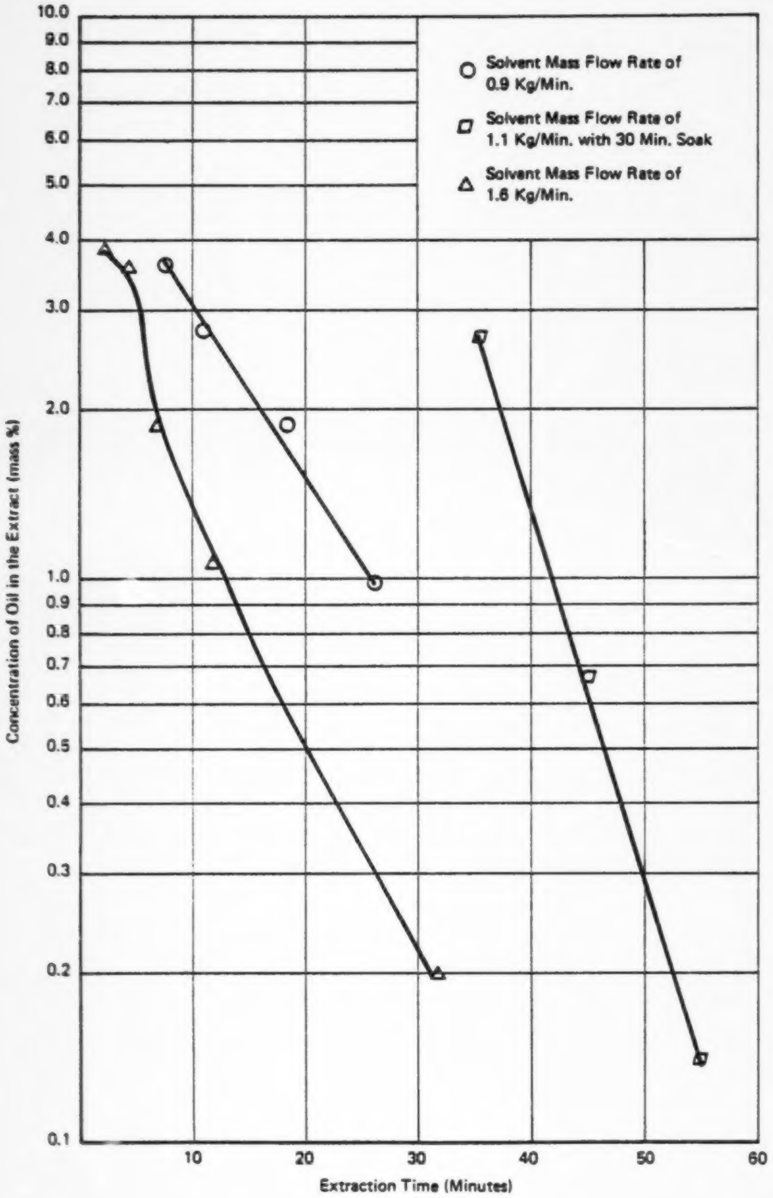


FIGURE 2 OIL CONCENTRATION IN MILL SCALE EXTRACT AS A FUNCTION OF TIME

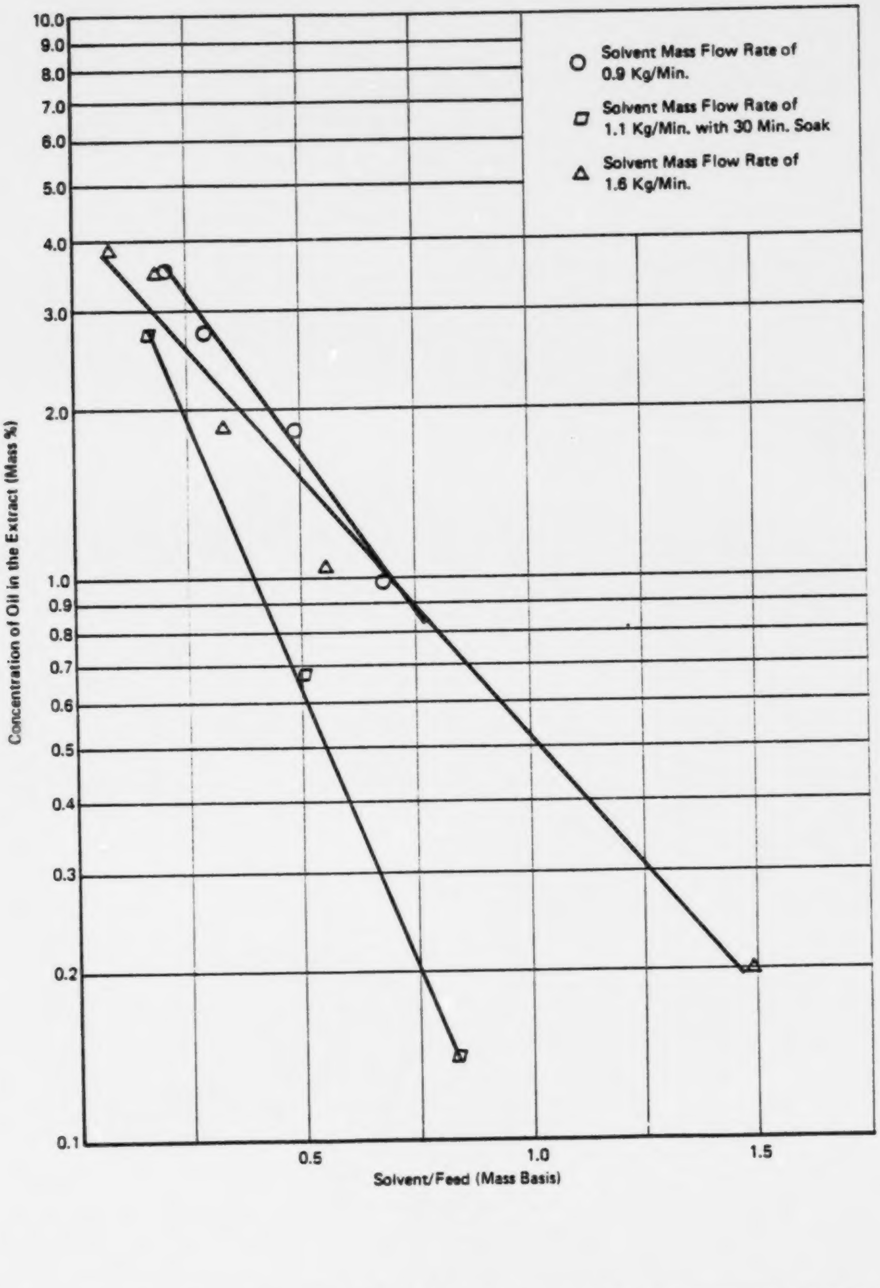


FIGURE 3 OIL CONCENTRATION IN MILL SCALE EXTRACT AS A FUNCTION OF SOLVENT TO FEED RATIO

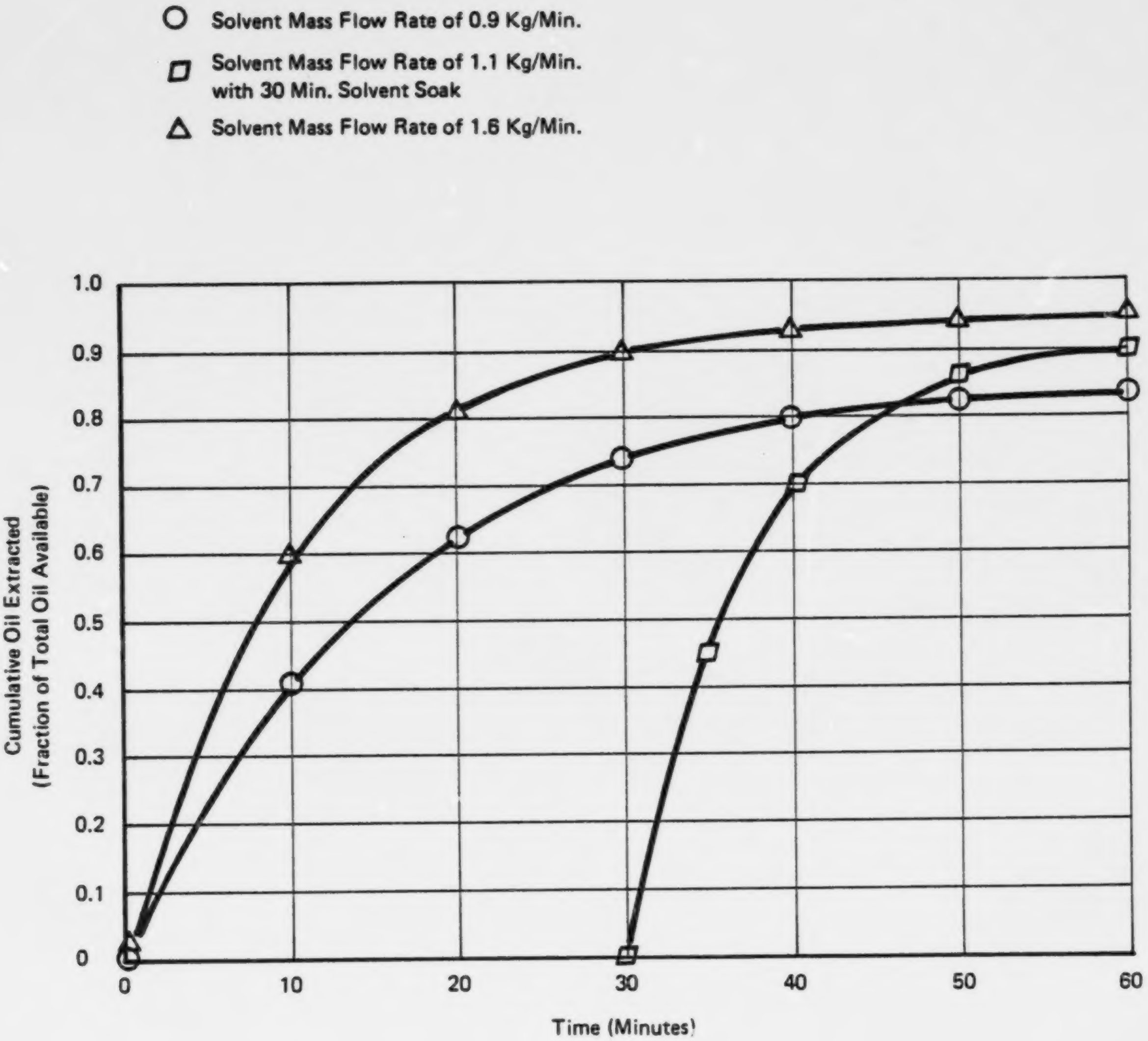


FIGURE 4 CUMULATIVE OIL EXTRACTED FROM MILL SCALE AS A FUNCTION OF TIME

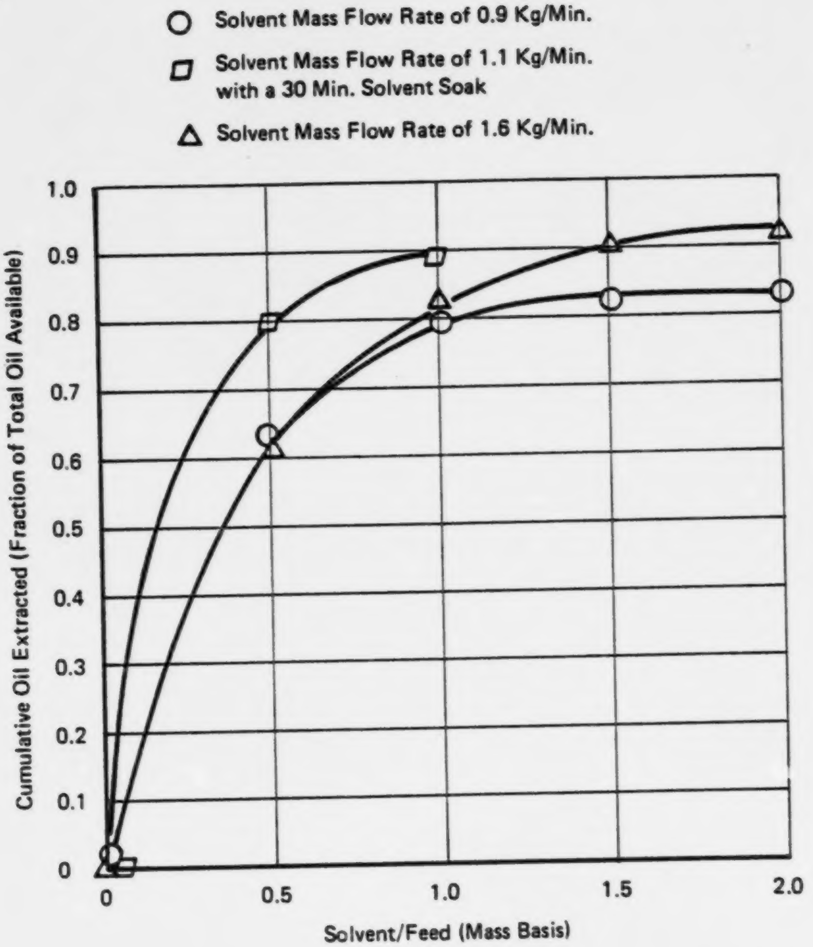


FIGURE 5 CUMULATIVE OIL EXTRACTED FROM MILL SCALE AS A FUNCTION OF SOLVENT TO FEED RATIO

RESULTS

The results of six pilot plant extractions are shown in Table 2. The feed oil concentration averaged 1.2 +/- 0.2%. In all but one case, residual oil after extraction was reduced to 0.2% or less. An analysis of the oil collected in our laboratory from the same material is presented in Table 3. It can be seen that this oil has a high heating value and could be burned as fuel. It may also be possible to recycle this oil as a lubricant. The de-oiled mill scale is suitable for sintering.

The extract stream was sampled periodically during the upflow experiments, and the samples were analyzed for oil concentration. The oil concentration is plotted against time in Figure 2 and as a function of solvent-to-feed ratio on a mass basis in Figure 3. The concentrations in Figures 2 and 3 together with flowrates have been used to calculate the cumulative oil extracted which is plotted in Figures 4 and 5 as a function of time and solvent-to-feed ratio.

The concentration of oil in the extract stream decreased continuously as each extraction experiment progressed as shown in Figures 2 and 3. In general, a decrease in the flow rate gave a decrease in the rate at which the concentration of oil in the extract dropped off (see Figure 2). The large shift of the curve when the flow rate was 1.1 kg/min is due to the soaking period during which no extract was taken off.

The extracted oil concentration as a function of the solvent-to-feed ratio graph (Figure 3) shows that the extracted oil is recovered with lower solvent usage when the mill scale is soaked in solvent prior to extraction.

In Figure 4, the total oil extracted is plotted against time; this is the calculated area under the curves in Figure 2. The mill scale is de-oiled in the shortest time period when the highest solvent flow rate was used, with 90% oil extraction achieved in about 30 minutes and 95% in 50 minutes.

TABLE 2

MILL SCALE EXTRACTION RESULTS

Flow Direction	Extraction Time (minutes)	Solvent Flow Rate (kg/min)	Solvent to Feed Ratio (Mass Basis)	Oil Content (Mass Percent) Feed	Oil Content (Mass Percent) Residue	Extraction Efficiency (%)
Up	160	0.9	4.0	1.2	0.4	66
Up	94	1.6	4.0	1.2	0.1	92
Up	30*	1.1	1.1	1.0	0.2	80
Down	90	1.0	2.5	1.4	0.1	93
Down	62	1.4	2.6	1.2	0.1	92
Down	83	0.5	1.3	1.0	0.2	80

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*Soak period of 30 minutes prior to the 30 minute extraction.

TABLE 3

ANALYSIS OF OIL EXTRACTED FROM MILL SCALE

Property	Analysis
Elemental Analysis:	
Carbon (%)	86.16
Hydrogen (%)	12.42
Nitrogen (%)	0.05
Sulfur (%)	0.78
Thermal Gravimetric Analysis (TGA):	
Moisture and Volatile Organics (%)	1.2
Combustibles – Liquids and Solids (%)	96.4
Ash (600°C) (%)	2.4
Density, 22°C g/ml	0.915
Viscosity (cp)	390
Flashpoint (°C)	>260
Heating Value (Btu/lb)	19,227
(cal/g)	10,681

Figure 5, which is based on the same data as Figure 3, shows that the soaking allowed the greatest degree of extraction with equivalent solvent quantities. The first few points of the "no soak" extractions are virtually identical. However, as the extraction approached completion, the higher velocities continued to extract oil while more residual oil was left on the mill scale exposed to the lower velocities.

PROCESS DESIGN AND ECONOMICS

A preliminary design was prepared for a mill scale de-oiling plant for the purpose of a process feasibility study. The design basis was taken from the conditions at an operating steel mill and from experimental data.

The plant capacity is 90,000 metric tons of mill scale per year, or 12.5 tons per hour. Oil content of the mill scale is 5.0%. Design criteria are given in Table 4, while operating costs are summarized in Table 5. Equipment and total capital cost are given in Table 6. The results of cost analysis, which are encouraging, are summarized below:

1. The capital investment for the de-oiling plant is estimated at $1.75 million.
2. The operating cost is projected to be $0.5 million per year or $6 per ton of mill scale.
3. Based on values of the recovered oil of 60 cents/gallon, the de-oiled mill scale of $12/ton, and no value for the 5% oil mill scale, the de-oiling plant yields a net profit of $1.5 million per year. The payout time for the $1.75 million investment is about 15 months.

CONCLUSIONS

Condensed gas extraction of steel mill scale has been demonstrated at the pilot plant stage and is technically feasible and economically attractive. The processing of these wastes presents an opportunity to recover significant amounts of raw materials which are currently a disposal problem. In addition to reprocessable iron, lubricating oils can be recovered. If not suitable for reuse as a lubricant, this reclaimed oil can be used as fuel. The payback on a 90,000 metric ton per year plant of about 15 months is quite attractive. Work on process development will continue with commercial scale plants based on this technology anticipated in the near future.

TABLE 4

MILL SCALE DE-OILING PLANT DESIGN CRITERIA

• Feed	Temp.:	10-35°C (50-100°F)
	Oil Content:	3-6%
	Moisture:	5-10%
	Particle Size:	–325 to +4 mesh
• Product Quality Millscale	Oil Content:	< 0.1%
	Moisture:	5-10%
	Iron + Iron Oxide: (dry basis)	> 99%
Oil	Oil Content:	> 98%
	Use	Fuel
• Solvent Recovery	99.98%	
• Plant Capacity	90,000 Tons per Year	
• Extraction Temperature/Pressure	21-27°C (70-80°F)	700-800 kPa (100-120 psi)

TABLE 5

OPERATING COST FOR MILL SCALE PLANT

(Basis: 90,000 Tons Per Year De-Oiled Mill Scale)

	Annual Cost
Labor	$ 210,240
Supervision	26,280
Electricity	115,000
Cooling Water	2,420
Solvent:	
Solvent Make-Up	50,400
Maintenance	70,000
Taxes and Insurance	35,000
	$ 509,340
Credit on Recovered Oil (1.5 x 10^6 Gallons at $.60/gallon)	($ 900,000)
Credit on Recovered Mill Scale (90,000 Tons at $12/Ton)	($1,080,000)
Net Profit	$1,470,660
Payout Time (for $1,752,400 Capital)	One Year, Three Months

TABLE 6

MILL SCALE DE-OILING PLANT EQUIPMENT AND FACILITY COSTS

Extraction Columns	$ 100,000
Compressors	175,000
Solvent Stripper	20,000
Heat Exchangers	90,000
Decanter, Flash, & Separator Drums	55,000
Pumps	20,000
Tanks/Bins	20,000
Conveyors	15,000
Total Equipment	$ 495,000
Total Installed Facility Cost	$1,750,000

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IS THERE MORE TO ROAD DUST SUPPRESSANTS THAN DUST CONTROL?

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ABSTRACT

Control of dusts from open sources, particularly unpaved roads, is advantageous to the iron and steel industry since this allows some trade-offs under EPA's "Bubble Policy." Studies have been made on the effectiveness of chemical road dust suppressants and on the cost-effectiveness of these chemicals. Data on the possible environmental consequence of using these materials is, however, quite limited. This study was initiated as a screening test to determine whether or not more detailed work was indicated. Five commercial products were examined for indications of potential environmental problems.

The results indicated that the potential exists for environmental problems due to heavy metal content of some suppressants, polynuclear aromatic hydrocarbons content in some suppressants, and moderate toxicity (Chinese hamster clonal) in all of the products examined. None of the products tested exhibited any mutagenic activity (Ames/Salmonella) due to the toxicity noted above.

Although the research described in this paper was funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

INTRODUCTION

BACKGROUND

For several years, particularly since EPA promulgated the Alternate Emission Reduction Option Policy (the "Bubble") in late 1979, the iron and steel industry has expended both effort and money to control fugitive dusts from open sources. Previous studies have demonstrated that a significant fraction of the total suspended particulates in ambient air could be attributed to nonpoint sources such as unpaved roads. Both EPA and industry have conducted studies of the effectiveness and cost-effectiveness of various types of road dust suppressants. As a consequence of these studies and the economic benefit to be gained under the "Bubble" policy from controlling road dusts, many products are now marketed for the application and are in use by the industry.

Many of the chemical and road dust suppressants are either waste products of another industry or are formulated from such a waste product. Recently, some concern has been expressed that little is known about the possible environmental impacts of using these products.

OBJECTIVE

The objective of this study was to conduct a limited screening of some of these products for characteristics that would indicate whether or not this concern should receive more research attention.

PRODUCTS SELECTED FOR TESTING

A list of commonly used (as of 1983) chemical road dust suppressants was provided by EPA. The manufacturers of most listed products were contacted by phone, and the nature of the project was described. Requests were made of each representative contacted for research size (1 gallon) samples. Samples were received from only one of the companies contacted. Three of the products, Coherex®, Resinex®, and Petro Tac were obtained directly from end users in the steel industry. Insufficient time remained in the contract to purchase those not received.

The products received and tests are listed in Table 1.

EXPERIMENTAL

Each of the "as received" samples was homogenized and separated into three portions for metals analysis, organic analysis, and biological analysis. Details of the procedures used in these analyses are given below.

TABLE 1. PRODUCTS TESTED

Product	Type	Source of Sample
1. Oil Well Brine (Normal product marketed)	Salt (NaCl)	Clinton Formation, Ohio Universal Energy Services, Inc.
2. Oil Well Brine (Pretreated--experimental)	Salt (NaCl)	Clinton Formation, Ohio Universal Energy Services, Inc.
3. Coherex®	Petroleum resin	Supplied by steel industry users (see Note)
3. Resinex®	Petroleum resin	Supplied by steel industry users (see Note)
4. Petro Tac	Asphalt Emulsion	Supplied by steel industry users (see Note)

Note: Because the samples were not collected by RTI and were not obtained directly from the manufacturer, RTI cannot discount the possibility of adulteration or contamination.

PROCEDURE FOR METALS DETERMINATION

Sample Preparation

The dust suppressant samples were treated as oil samples and were worked up according to a procedure obtained from Instrumentation Laboratories, Inc. for the analysis of total metals in used oil. Each dust suppressant sample was worked up and analyzed in triplicate.

A 2.00 g aliquot was weighed into a polypropylene screw cap bottle. Four-tenths mL of a mineral acid mixture (nitric acid:hydrochloric acid:hydrofluoric acid::1:8:1 by weight) was added. Samples were capped and placed in a 40°C ultrasonic shaker for 15 min. After shaking, 14.15 mL of a solvent mixture (kerosene:neodol 91-6::13:7 by volume) was added. Conostan metals in oil standards were treated identically and used as calibration standards.

The well brine samples required no manipulation other than a minimum dilution of 1/5th. This was necessary to keep total dissolved solids within instrumental tolerances.

Analysis of Well Brine Samples

The well brine samples were analyzed by ICAP under three separate programs. Semiquant is a commercially available program from Instrumentation Laboratories, Inc. for use with their ICAP instruments. It is designed to provide rapid, semiquantitative analysis of unknown samples for a wide range of elements. Once optimized for a particular machine, semiquant results may be considered, in general, as better than ±50 percent.

Since Semiquant does not analyze for mercury, program "1883-16 Aqueous Hg" was developed to fill this gap in the results. Program "1883-16 Aqueous" was developed to confirm positive results for boron and strontium. Both "1883-16 Aqueous" and "1883-16 Aqueous Hg" were developed under the standard operating system in which each line is calibrated against a standard solution.

Analysis of Dust Suppressant Samples

The dust suppressant samples were analyzed by ICAP under three separate programs. "Oil Squant 1.0" is "Semiquant" modified for organics and calibration levels. In addition, where a metal in oil standard was available, the intensity ratio was modified for the corresponding line.

Program "Kerosene and Oil 1.2" is routinely used in this laboratory for the analysis of the RCRA metals dissolved in oil (as opposed to total metals). It was used without modification. This analysis was included primarily for mercury. It also provides for confirmation of the arsenic analysis from "Oil Squant 1.0." Program "Oil Confirmation 1" was developed to provide confirmatory analysis for certain positive results from "Oil Squant 1.0."

PROCEDURE FOR ORGANIC DETERMINATION

Extraction and Fractionation of Organic Dust Suppressants

An aliquot of the neat material was dissolved in 50 mL of methyl-tert-butyl ether by vortexing. Any insoluble material was removed by filtration or decantation. The dissolved sample was subjected to an acid-base partition from which acid, base, and neutral fractions were obtained.

Partition Into Acids, Bases, and Neutrals

The methyl-t-butyl ether extract was extracted three times with 100 mL of 5 percent H_2SO_4. The combined aqueous layers contained the bases, and the neutrals and acids remained in the organic layer. The base fraction was adjusted to pH 13 with 40 percent KOH, then extracted with 100 mL methylene chloride. The methylene chloride layer was dried with anhydrous sodium sulfate, then concentrated to 5 mL and subjected to mass determination.

The acids/neutrals in methyl-t-butyl ether were extracted with 100 mL of 5 percent NaOH four times. The combined aqueous layers containing the acids were adjusted to pH 1 with $6\underline{M}$ H_2SO_4, then extracted with 100 mL methylene chloride three times.

The acids in methylene chloride were dried with anhydrous sodium sulfate and concentrated to 5 mL. The mass of the fraction was determined. The neutrals in methyl-t-butyl ether (following a 5 percent NaOH wash) were dried with anhydrous sodium sulfate and concentrated to 5 mL. The mass of the fraction was determined.

Subfractionation of the Neutrals Fraction

An aliquot of each neutral fraction equivalent to approximately 10 mg (0.2-0.5 mL) was added to a silica Sep-Pak (Waters Assoc.). The solvent (methyl-t-butyl ether) was removed under a gentle N_2 stream. The Sep-Pak was then eluted with 10 mL of each of the following solvents: hexane, 1:1 hexane/methylene chloride, methylene chloride, and 1:9 methanol/methylene chloride. Each 10 mL fraction was collected and stored at -20°C until further analysis was required.

Thermogravimetric Analysis of Neat Materials

A small aliquot (14-23 mg) of each neat organic dust suppressant received (Petro Tac, Resinex, and Coherex) was subjected to thermogravimetric analysis (TGA) to evaluate volatility of the materials. The instrument used was a Perkin-Elmer TGS-2 Thermogravimetric system with a helium flow rate of 43.5 mL/min. Conditions were as follows: a temperature, 50°C; final temperature, 700°C; heating rate, 40°C/min; cooling rate, 160°C/min. The loss in mass was plotted versus temperature.

GC Screening

The hexane subfractions of the three organic dust suppressants' neutral fractions were screened by capillary GC. A window for screening for PNAs was set by the retention times of naphthalene and perylene. Three other PNAs of intermediate retention were included in the standard: anthracene, fluoranthene, and triphenylene.

PROCEDURES FOR BIOASSAY

Ames/Salmonella Mutagenicity Assay

The five chemical dust suppressants were evaluated for mutagenic potential in the Ames/*Salmonella* assay with Strains TA98 and TA100, with and without S9 addition. The S9 liver activation system was obtained from Aroclor-induced male Sprague-Dawley rats. A 10 percent S9 mix (0.1 mL S9 plus 0.9 mL of buffer and cofactors) was prepared and 500 µL of the 10 percent S9 mix were added per plate. Five dose levels were applied (200, 100, 50, 10 and 2.0 µL/plate) with triplicate plates per dose level tested in the standard plate incorporation assay. The top two doses (200 and 100 µL/plate were not diluted and were added to the plate neat; the remaining three doses (50, 10 and 2 µL/plate) were diluted to 100 µL with dimethyl sulfoxide or water, as appropriate. Concurrent solvent, negative and positive controls, in addition to sterility controls and a strain genetic marker check (histidine dependence, crystal violet and ultraviolet sensitivity, and ampicillin resistance) were performed with each assay.

The positive control compounds for TA98 were 2-nitrofluorene at 2 and 10 µg/plate (-S9) and 2-aminoanthracene at 1 and 2.4 µg/plate (+S9), and for TA100: sodium azide at 2 and 10 µg/plate (-S9) and 2-aminoanthracene at 1 and 2.5 µg/plate (+S9). A positive mutagenic response was defined as a two-fold increase in revertant colonies at a minimum of three increasing dose levels (Brusick et al. 1980). Data were statistically analyzed for the mean, standard deviation and mutagenic ratio at each positive and solvent control and test dose. Samples were evaluated for their minimum effective concentration (MEC), and mutagencity was ranked as high, moderate, low or nondetectable based on the IERL ranking criteria (Brusick et al., 1980).

CHO Clonal Toxicity Assay

The dust suppressants were tested at five dose levels, triplicate plates per dose level. The two aqueous liquids were tested at 600, 300, 100, 60 and 6.0 µL/mL, and the three nonaqueous liquids (Coherex®, Resinex®, and Petro-Tac) were tested at 20, 10, 5, 2 and 0.2 µL/mL. Both types of samples were added directly to the plates and were not diluted into solvent. Total volume in the test plates was kept constant at 5 mL per plate by adjusting the volume of media.

Negative (untreated) and positive control plates were conducted concurrently with the assay. Cadmium chloride was the positive contol, and was tested at $1x10^{-6}$ M and $2x10^{-6}$ M. Control plates were tested in triplicate at each dose level.

The medium utilized was HAM's F12 with 10 percent (V/V) fetal bovine serum and 100 units/mL of penicillin and 100 µg/mL of streptomycin. Chinese hamster ovary cells (CHO-K1) in the exponential growth phase were removed from the growth flask, were plated at 200 cells/plate in 5 mL of media, and were allowed to attach for six hours. Sample and positive control doses were added for 24 hours at which time the medium was removed, and the cells were washed three times with warm (37°C) Dulbecco's phosphate-buffered saline before fresh media was added. Plates were incubated at 37°C for 10 days, then stained with Giemsa and manually counted.

RESULTS

METALS

The results of all analyses are shown in Tables 2 and 3. The blanks in the detection limit column of Table 3 are due to elements which are not part of the Conostan S-12 metals in oil mixture. A "not detected" result for these elements implies a negative or zero result after the mean was corrected for a metal blank oil. No thallium in oil standard is available. Thus, a confirmatory analysis could not be made nor could the intensity ratio for this line be adjusted. The results for these elements should be viewed as positive

TABLE 2. ANALYTICAL RESULTS FOR WELL BRINE SAMPLES
All results in ppm (referred to original sample)

	PROGRAM							
	Semiquant			1883-16 Aqueous Hg			1883-16 Aqueous	
Element	Detection Limit	As Received	After Cleanup	Detection Limit	As Received	After Cleanup	As Received	After Cleanup
As	1.5±	N.D.	N.D.	-	-	-	-	-
Zn	0	0.75	1.8	-	-	-	-	-
Cd	0	N.D	0.05	-	-	-	-	-
Pb	1.5	N.D.	N.D.	-	-	-	-	-
Ni	0.21	N.D.	N.D.	-	-	-	-	-
Ba	0	1.75	1.6	-	-	-	-	-
Fe	0	82.1	N.D.	-	-	-	-	-
Mn	0	55.5	48.5	-	-	-	-	-
Mg	0	4,230	4,330	-	-	-	-	-
V	0.15	N.D.	N.D.	-	-	-	-	-
Be	0	N.D.	N.D.	-	-	-	-	-
Cu	0.21	N.D.	0.25	-	-	-	-	-
Al	0.33	5.35	8.15	-	-	-	-	-
Ba	-	1.9	1.9	-	-	-	-	-
Na	1.5	56,900	60,900	-	-	-	-	-
Li	0	70.5	83.5	-	-	-	-	-
Sr	0	1,280	1,300	-	-	-	1,400	1,560
Bi	2.1	N.D.	N.D.	-	-	-	-	-
B	0.15	37.2	38.1	-	-	-	41.5	39.6
Si	0	3.5	3	-	-	-	-	-
Co	0	N.D.	N.D.	-	-	-	-	-
Pt	1.5	N.D.	N.D.	-	-	-	-	-
Ag	0.75	N.D.	N.D.	-	-	-	-	-
Ca	0	36,300	36,600	-	-	-	-	-
Pd	0.33	N.D.	N.D.	-	-	-	-	-
Se	0	N.D.	0.5	-	-	-	-	-
Mo	0.21	N.D.	N.D.	-	-	-	-	-
Cr	0	N.D.	0.05	-	-	-	-	-
Sb	0	N.D.	N.D.	-	-	-	-	-
Tl	5.4	N.D.	N.D.	-	-	-	-	-
Hg	-	-	-	0.44	0.62	N.D.	-	-

TABLE 3. ANALYTICAL RESULTS FOR DUST SUPPRESSANT SAMPLES

Element	Oil Squant 1.0 (µg/g)				Kerosene and Oil 1.2 (µg/g)				Oil Confirmation 1 (µg/g)			
	Dectection Limit	Resinex®	Coherex®	Petro Tac	Dectection Limit	Resinex®	Coherex®	Petro Tac	Detection Limit	Resinex®	Coherex®	Petro Tac
As	-	26	50.5	N.D.	7.5	N.D.	39.6	7.9	-	-	-	-
Zn	0.57	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Cd	0.48	N.D.	N.D.	N.D.	0.08	N.D.	N.D.	0.15	-	-	-	-
Pb	10.	N.D.	N.D.	N.D.	23	N.D.	N.D.	N.D.	2	N.D.	N.D.	N.D.
Ni	0.97	N.D.	N.D.	N.D.	-	-	-	-	0.5	N.D.	N.D.	N.D.
Fe	0.23	41.6	1.89	6.27	-	-	-	-	-	-	-	-
Mn	0.04	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Mg	0.23	7.19	16.64	2.24	-	-	-	-	-	-	-	-
V	0.42	N.D.	N.D.	1.71	-	-	-	-	0.3	N.D.	N.D.	N.D.
Be	-	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Cu	0.53	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Al	4	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Ba	0.06	N.D.	N.D.	N.D.	0.07	N.D.	N.D.	N.D.	-	-	-	-
Na	4.5	25.3	17	616	-	-	-	-	-	-	-	-
Li	-	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Sr	-	N.D.	0.05	N.D.	-	-	-	-	-	-	-	-
Bi	-	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
B	0.20	0.32	1.10	N.D.	-	-	-	-	0.14	N.D.	1.27	N.D.
Si	0.36	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Co	-	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Pt	-	0.01	.033	.023	-	-	-	-	-	-	-	-
Ag	0.70	N.D.	N.D.	N.D.	0.59	N.D.	N.D.	0.65	-	-	-	-
Ca	1	6.39	88.0	6.55	-	-	-	-	-	-	-	-
Pd	-	0.03	.027	.04	-	-	-	-	-	-	-	-
Se	-	N.D.	N.D.	N.D.	0.13	0.74	N.D.	1.57	-	-	-	-
Mo	3.2	N.D.	N.D.	N.D.	-	-	-	-	-	-	-	-
Cr	1.7	N.D.	N.D.	N.D.	0.19	N.D.	N.D.	8.95	-	-	-	-
Sb	-	0.2	0.5	N.D.	-	-	-	-	-	-	-	-
Tl	-	2.5	1.93	2.53	-	-	-	-	-	-	-	-
Hg	-	-	-	-	6.8	24.3	38.2	N.D.	3.8	N.D.	8.27	5.18

relative to the blank level but with no confidence attached to the actual numbers.

ORGANICS

Extraction and Fractionation

Fractionation of the organic dust suppressants with subsequent mass determination showed that the largest extractable mass was in the neutrals fraction (Table 4). Petro Tac was the only material in which the acid fraction had a measurable mass. The bases accounted for less than 1 percent of the extracted masses of each of the two materials in which the bases had a measurable mass. These data are in agreement with the expectation that these materials would have a high hydrocarbon content. The fractionation recoveries ranged from 12-60 percent. The low recovery in Petro Tac is in large part due to a significant particulate content which was filtered from the crude extract, but whose mass was not determined. The losses in the other two materials may be due to the presence of water-soluble components.

Thermogravimetric Analysis

Thermogravimetric analysis of the neat samples indicated that greater than 50 percent of the samples masses were volatilized at 320°C. At 500°C, essentially 100 percent of the masses of Resinex® and Coherex® were lost, and, by 600°C, 93 percent of Petro Tac's mass was lost. Since at least 50 percent of these materials volatilized by 320°C, the upper limit for the GC capillary column to be used for their analysis, they were considered amenable to GC analysis.

GC Screening

Gas chromatography of the hexane subfraction of Petro Tac neutrals produced a complex pattern in which PNAs may be present. The hexane subfraction of Resinex neutrals exhibited a pattern characteristic of homologous series of aliphatic hydrocarbons. The Coherex neutrals hexane subfraction produced a broad envelope with no well defined peaks of significant intensity. GC/MS analysis would be required for the Petro Tac fraction to confirm the presence of PNAs and for the Resinex fraction to confirm the aliphatic hydrocarbon homologues.

As noted above, none of these materials completely volatilize at the upper limit of the GC column used. Thus, this analysis does not exclude the possibility of other environmentally significant compounds being present.

BIOASSAY

Ames/Salmonella Mutagencity Assay

Mutagenic ranking and minimum effective concentration (MEC) for each of the samples are contained in Table 5. Mutagencity was not detected in any of the samples under the test conditions. However, it should be noted that all samples exhibited toxicity in the CHO test. Thus, these results cannot be interpreted as evidence that the materials are nonmutagenic. Tests with live animals would be required to demonstrate lack of mutagenic activity.

TABLE 4. EXTRACTION/FRACTIONATION EFFICIENCIES FOR THREE ORGANIC DUST SUPPRESSANTS

Sample	% Recovery[a]	% Bases	% Acids	% Neutrals
Petro Tac	12	0.08[b] (0.7)[c]	2.3[b] (20)[c]	9.5[b] (80)[c]
Resinex®	39	0[b] (0)[c]	0[b] (0)[c]	39[b] (100)[c]
Coherex®	60	0.13[b] (0.04)[c]	0[b] (0)[c]	60[b] (100)[c]

[a] % recovery = mass acids + mass bases + mass neutrals/starting mass.

[b] Absolute % fraction = mass fraction/starting mass.

[c] Normalized % fraction = mass fraction/sum of masses of three fractions.

TABLE 5. MINIMUM EFFECTIVE CONCENTRATION (MEC) AND MUTAGENIC RANKING OF FIVE CHEMICAL DUST SUPPRESSANTS IN THE AMES/SALMONELLA MUTAGENESIS ASSAY

Compound	MEC (μL/plate)	Ranking of[a] Mutagenic Activity
Coherex®	>10	Nondetectable[b]
Oil Well Brine (untreated)	>200	Nondetectable
Oil Well Brine (treated)	>200	Nondetectable
Resinex 60®	>10	Nondetectable[c]
Petro Tac	>200	Nondetectable

[a] IERL criteria, Brusick et al., 1980.

[b] Contamination was present at the three highest doses (200, 100, and 50 μg/plate). Sample could not be sterilized due to the sandy nature of the sample. Nondetectable at maximum applicable dose of 10 μL/plate.

[c] Toxicity was present at three highest doses (200, 100, and 50 μg/plate). Nondetectable at maximum applicable dose of 10 μL/plate.

Three of the samples had an MEC greater than 200 μL/plate, which resulted in a ranking category of nondetectable [oil well brine (treated and untreated) and Petro Tac]. Petro Tac did produce a mutagenic ratio greater than 2.0 at one dose (2 μL/ML) with TA100 and S9 addition, but this response was not dose related. Resinex® demonstrated toxicity at the three highest doses with both strains and activation conditions, and therefore the ranking was nondetectable at the maximum applicable dose of 10 μL/plate. Toxicity of Resinex was indicated by a reduction in revertants below the spontaneous background value. The fifth sample, Coherex®, was contaminated at the three highest doses (200, 100 and 50 μL/plate), which results in a ranking of nondetectable at the maximum applicable dose of 10 μL/plate. The sandy nature of the sample precluded sterilization.

CHO Clonal Toxicity Assay

EC$_{50}$ values and toxicity rankings from the CHO clonal toxicity assay are contained in Table 6. All five chemical dust suppressants were of moderate toxicity, as defined by the IERL ranking criteria for aqueous and nonaqueous liquids. The absolute cloning efficiency [the solvent control compared to the number of cells plated (200)] was 63 percent. The positive control, cadmium chloride, had an EC$_{50}$ value of $>1 \times 10^{-6}$M.

The EC$_{50}$ values were estimated as described in Standard Methods (1976). The EC$_{50}$ values and confidence intervals could not be calculated by formal probit analysis because these data did not contain at least two partial mortalities. The straight-line graphical interpolation method provides results that are similar to results by probit analysis [Standard Methods (1976)].

CONCLUSIONS AND RECOMMENDATIONS

It must be recognized that the conclusions and recommendations presented here are based on analysis of a small subset of the products available. Furthermore, most of the samples were obtained from end users rather than the manufacturer.

Conclusions

1. None of the samples contained sufficiently high concentrations of heavy metals to be of obvious environmental concern. There are sufficient concentrations and variability in several heavy metals to warrant further study.

2. Only one of the samples contained components that could be polynuclear aromatic hydrocarbons. (Identity of the components was not established.) However, the samples were not completely volatilized under the GC operating conditions.

3. All samples tested received a moderate toxicity ranking by the Chinese hamster ovary (CHO) clonal toxicity assay.

4. Mutagenicity was not detected in any of the five samples (Ames/Salmonella) due to toxicity and/or contamination. This test did not produce conclusive evidence as to the potential mutagenicity of the product.

Recommendations

It is recommended that a more comprehensive study of road dust suppressant chemicals be initiated since moderate toxicity was detected for all five products tested in the CHO clonal toxicity assay. It is recommended that all formulations in use or proposed for use be evaluated by bioassay techniques prior to detailed chemical analysis since chemical composition did not appear to correlate with toxicity. It is further recommended that all five compounds screened in this study be evaluated in the in vivo test in rodents.

REFERENCES

Brusick, D. J., R. R, Young, C. Hutchinson, A.G. Dilkas and T. G. Gexo, (1980) IERL-RTP Procedures Manual : Level 1 Environmental Assessment Biological Tests, EPA-RTP, PP 1-158.

Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition (1976), M. Franson (ed.). Section 801F. Calculating, Analyzing, and Reporting Results of Bioassays, pp. 731-740.

TABLE 6. EC_{50} VALUES AND TOXICITY RANKING OF FIVE CHEMICAL DUST SUPPRESSANTS IN THE CHO CLONAL TOXICITY ASSAY

Compound	EC_{50}[a] (μL/mL)	Ranking of Toxicity
Coherex® (nonaqueous liquid)	0.6	Moderate
Oil Well Brine (untreated) (aqueous liquid)	20.8	Moderate
Oil Well Brine (treated) (aqueous liquid)	16.5	Moderate
Resinex 60® (nonaqueous liquid)	0.6	Moderate
Petro Tac (nonaqueous liquid)	0.6	Moderate

[a] Determined by inspection of dose responses graph of relative survival (x-axis) versus sample concentration in μL/mL on y-axis (Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, 1976, pp. 731-739.

[b] Brusick et al., 1980.

COST AND RISK: A CROSS-MEDIA LOOK AT CONTROL IN THE IRON AND STEEL INDUSTRY

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ABSTRACT

For several years, regulators have been concerned that control of pollution in one environmental medium might have the effect of simply transferring the pollution to another environmental medium where its effect might be no less harmful. For example, various air pollution control devices produce wastewater and dust that must then be treated and disposed of or discharged. Generally, regulatory decisions about one medium do not systematically address effects that may occur in another medium as a result of pollution control, or the potential cost of reducing those secondary effects.

Starting with the assumption that there are differences in the risks of various pollutants and, many times, variations in the risk of one pollutant depending upon the receiving environmental medium, the Integrated Environmental Management Division (IEMD) at the Environmental Protection Agency began, in 1982, to develop a methodology for evaluating across media the costs and risks of controlling pollution sources in particular industrial sectors. Choosing the iron and steel industry as the subject of the pilot study, IEMD developed a method for evaluating the probable costs and probable reductions in health and environmental effects associated with numerous air, water, and solid waste controls. The methodology tied together pollution data, exposure data and effects data, and tracked transfers of pollution between media, evaluating numerous controls in terms of cost per "unit of risk" reduced. "Unit of risk" is a summary measure based on the projected weighted incidence of a variety of health and environmental effects.

This paper reviews the general methodology, its limitations, the improvements made to date, the results of the iron and steel pilot study, other applications of the approach, and ways that this approach can best be used in control decisions made by plant managers and regulators. This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

METHODOLOGY

The methodology assumes that health and environmental impacts are comparable across media and that pollutant impacts on the same receptors (people, crops, etc.) can be summed. This makes it necessary to assume that all the health effects attributable to environmental pollution can be quantified and compared with one another and that all the environmental (nonhealth) effects can be similarly treated.

The iron and steel integration model developed for IEMD by Putnam, Hayes, and Bartlett, Inc. (PHB) consists of a computer program that calculates cost-effectiveness ratios for individual control options. The emission reductions associated with each control option are related to exposure scenarios and then to a number of health and ecological effects, which are weighted and summed. The result is the "effectiveness" side of the cost-effectiveness ratios that are estimated for between 150 and 200 control options. Throughout the analysis, the transfer of pollutants between media is tracked and calculated for "negative" effectiveness where applicable.

IEMD's original work on the iron and steel industry focused only on the northern Ohio steelmaking region. The first step in developing the analytic framework was to pull together all the production processes common to the industry in the case study area; the process residuals discharged into air, water, and on land; the various exposure routes to people and biota; and the health and environmental effects associated with exposure to the various substances. These data sets were assembled in a computer model that was used to rank control options across media in terms of cost per unit of health or environmental risk reduced, i.e. cost-effectiveness, tracking intermedia transfer throughout the calculations. Health and ecological effects were analyzed separately.

Later, to test the national implications of the Ohio case study results, variations in exposure parameters such as population, terrain, meteorology, and characteristics of surface water and groundwater supply were used to develop additional environments, or "reference" environments, that roughly reflect other major steelmaking regions in the United States. By studying these generic, or "reference" environments, IEMD was able to demonstrate how much the cost-effectiveness of controls might vary with site-specific characteristics.

Plant-specific data were used where possible to estimate production levels and pollution controls in place. Costs, removal efficiencies for pollution controls not currently in place, and intermedia impacts were estimated by engineering firms. State permit information and federal survey data were used to determine current emissions, wastewater discharges, and waste generation. Twenty-five toxic and conventional pollutants were tracked in the analysis.

The general calculation used for evaluating the cost-effectiveness of control options$_{CO}$ is outlined below.

$$\frac{\text{COST}_{CO}}{\text{EFFECTIVENESS}_{CO}} = \frac{\text{ANNUAL OPERATING COSTS}_{CO} + \text{ANNUAL CAPITAL RECOVERY FACTOR}_{CO}}{\text{SUM OF CURRENT EFFECTS} - \text{EFFECTS}_{CO}\text{ AFTER INSTALLATION}}$$

Current effects, for the uncontrolled plant, and effects after installation of controls are estimated in the following way.

EFFECTS = PRODUCTION X POLLUTION X EXPOSURE X DOSE X RESPONSE

For example, for a control option that includes a dry air control combined with land disposal of residual dust, such as installing an electrostatic precipitator on an electric arc furnace (EAF), effects after installation would be estimated in the following way.

ANNUAL EAF PRODUCTION (TONS/YEAR)	X	POLLUTION REMOVED OR DISPOSED (PER TON OF PRODUCTION) BY POLLUTANT[1]	X	EXPOSURE FACTORS THAT RELATE NET POLLUTION TO AMBIENT AIR (ug/m^3) AND GROUND WATER (mg/l) CONCENTRATIONS BY POLLUTANT	X	DOSE TO POPULATION VIA INHALATION OR INGESTION BY POLLUTANT	X	RESPONSES ASSOCIATED WITH DOSE FOR EACH POLLUTANT[2]

1. In the EAF case, particulates, arsenic, chromium VI, flourine, flouride, iron, lead, nickel, and carbon monoxide are the pollutants that are tracked.

2. In this case, respiratory, carcinogenic, teratogenic, reproductive, neurotoxic, skin, renal, hepatotoxic, pulmonary, bone, and cardiovascular responses are associated with some dose.

The sum of potential responses is subtracted from the sum of responses associated with the uncontrolled plant and the net change in responses (or "effectiveness") is then divided into the cost of the control option, resulting in the cost-effectiveness ratio.

Exposure Modeling

The Industrial Source Complex Model (ISCM) and the Atmospheric Transport Model (ATM) were used for assessing exposure to air emissions. A simple dilution model was developed by PHB for water discharges, and a groundwater model was developed by Applied Science and Technology, Inc. and Thomas Prickett Associates to estimate leaching from landfills and transport of pollutants through soil to ground or surface water.

The ISCM model was used in the Ohio case study area to estimate unit concentrations for pollutants emitted from both stack and area sources at seven steel plants at 160 grid locations. To estimate concentrations in the reference environments, a single model plant was located in the center of each grid using the ATM model. Human population figures used in conjunction with ISCM and ATM were obtained from a data base included in EPA's Human Exposure Model (HEM) and from the SECPOP portion of the ATM model, respectively.

The surface water dilution model developed by PHB is a simple compartment water model similar to EPA's Exposure Analysis Modeling System (EXAMs). Average pollutant unit concentrations were calculated for each of nine compartments representing portions of the rivers in the case study area. One river with three compartments was used for reference environments. Drinking water intakes were modeled and populations drinking the water were estimated for the health analysis.

The methods employed to estimate the leaching of pollutants from landfills assume that the leaching of pollutants from landfills occurs because rainwater (and ground-water, if the landfill is partially below the water table) infiltrates the waste and, as it percolates through the material, becomes saturated with the pollutants present. It is assumed that (1) the percolating water carries away as much of each pollutant as the chemical's theoretical solubility in water will allow and that (2) all of the leachate eventually reaches the river. River flow rates were varied to estimate differences in resulting surface water concentrations in reference environments.

Effects Assessment

The health and environmental analyses were separate so that the value represented by the prevention of disease is not lumped in with such environmental values as visibility, crop damage, or water recreation. Each control was thus given two characteristic cost-effectiveness ratings based on the relative efficiency with which it reduces health risk or environmental damage.

To develop the health effects analysis the number of cases of each of seven major health effects attributable to a particular combination of pollutants and exposures was estimated. These potential incidences were weighted by a factor representing the relative severity of the particular health effect, calculated according to a formula that includes a subjective estimate of the quality of life lost and the number of workyears lost per case. Implicit in the quality of life scalar is consideration of health care costs, decrease in life expectancy, and the relative pain and suffering associated with the disease state. (It is important to note that the integrated computer model allows for the testing of several alternative weighting schemes.) Health effects that were tracked in the analysis included cancer, teratogenicity, renal effects, hepatotoxicity, neurological effects, reproductive effects and a category of other effects that included respiratory, cardiac, blood, and skin diseases.

For the separate analysis of environmental effects, dollar values are attributed to the various effects (crop damage, materials degradation, water recreational activities, commercial fishing, and visibility). The dollar values were based on direct and indirect economic effects. Market values were used where possible, e.g. commercial fishing, and willingness to pay surveys were used for effects such as visibility and recreational effects.

Reference Environment Analysis

To construct reference environments, the key parameters affecting the cost-effectiveness of pollution controls were identified and values for each variable were assigned to reflect conditions in other major steelmaking regions. These included pollution control cost, air exposure modeling, surface water exposure modeling, and groundwater exposure modeling parameters. The key parameters used to construct the reference environments included:

- Construction and Electricity Costs
- Current Pollution Controls
- Meteorological Conditions
- Terrain
- Size of Receiving Surface Water Bodies
- Background Pollutant Concentrations
- Population Distribution
- Drinking Water Usage Patterns
- Agricultural Land Use
- Commercial Fish Population

Four reference environments were constructed to reflect the range of typical exposure and cost conditions found in fifteen steelmaking areas.

Environment #1	Environment #2	Environment #3	Environment #4
Flat Terrain	Hilly Terrain	Hilly Terrain	Mountainous
High Population	Low/Moderate Population	Moderate Population	Low Population
Moderate/High Pollution	Moderate Pollution	High Pollution	Low Pollution
Large River	Average River	Moderate/Large River	Small River
Moderate/High Agriculture	Moderate/Low Agriculture	Low Agriculture	Low Agriculture

The computer analysis was then redone for each of the environments to determine how solutions might vary in different environments. This analysis helped in determining which controls appear to provide significant risk reductions for the cost regardless of plant location.

Sensitivity Analysis

Several sensitivity analyses were conducted in response to questions raised by reviewers from IEMD staff, scientific experts, Agency program officials, industry representatives and environmental groups. These included, among others, increasing the level of health or environmental protection sought; decreasing production levels; assuming promulgated regulations were already in place; simulating low flow surface water conditions; constructing a worst case reference environment; and changing health and water quality effect assumptions.

LIMITATIONS

Obviously there is uncertainty associated with many of the quantitative estimates included in this approach. For this reason it is extremely important to recognize that certain uses of the results are inappropriate. For example, in examining a ranking of thirty control options according to cost-effectiveness, one must remember that, due to the uncertainties, there may not be a great deal of difference between the cost-effectiveness of option one and option two, but there is likely to be a great deal of difference between options one and ten. IEMD estimated significant differences by examining the sampling distribution of the general cost-effectiveness ratio. Also, in using cost-effectiveness information in decision making, one must bear in mind the values that cannot as yet be quantified and the current pollution control requirements that have been set by federal and state statutes.

FINDINGS

The results of the iron and steel industry study confirmed the notion that the relative importance of control options changes with local conditions. Findings also revealed that several controls not currently regulated on a national basis appear to provide significant protection from potential effects for the cost, regardless of exposure conditions. These include air controls on slag crushing operations, blast furnace fugitives, coke quenching, and sintering, most of which are found on at least some steel plants.

After completing the pilot study, IEMD investigated ways to use this type of analysis in national regulatory policy decisions, reviewing what the analysis said about decisions made in the past, pending decisions, and future decisions of concern to federal and state regulators and to plant managers.

An example of the kind of analytic results this study produced is shown in Figure 1. The top ten controls in terms of lowest cost per unit of health risk are ranked under five sets of exposure conditions. In other words, the controls shown have the lowest cost per unit of risk reduced--the lowest cost-effectiveness ratio--given particular exposure conditions. This scenario is based on minimizing cost while maintaining the current level of health risk reduction.

	ENVIRONMENT #1	ENVIRONMENT #2	ENVIRONMENT #3	ENVIRONMENT #4	ENVIRONMENT #5
	Flat Terrain	Hilly Terrain	Hilly Terrain	Mountainous	Flat Terrain
	High Population	Low/Moderate Population	Moderate Population	Low Population	High Population
	Moderate/High Pollution	Moderate Pollution	High Pollution	Low Pollution	High Pollution
	Large River	Average River	Moderate/Large River	Small River	Large River & Lake
	Moderate/High Agriculture	Moderate/Low Agriculture	Low Agriculture	Low Agriculture	High Agriculture
1	Pickling Water	Pickling Water	Pickling Water	Pickling Water	Pickling Water
2	Lined Onsite Landfill	Cold Forming Water	Coke Quenching Air	Cold Forming Water	Coke Oven Gas Air
3	Cold Forming Water	Blast Furnace Water	Sintering Air	Blast Furnace Water	Electric Arc Air
4	Blast Furnace Water	Central Water Treatment	Cold Forming Water	Central Water Treatment	Coke Charging Air
5	Coke Charging Air	Hot Forming Water	Blast Furnace Water	Hot Forming Water	Coke By Products Air
6	Coke By Products Air	Coke By Products Air	Coke Charging Air	Coke Charging Air	Coke Quenching Air
7	Coke Quenching Air	Coke Charging Air	Coke By Products Air	Coke By Product Air	Blast Furnace Water
8	Central Water Treatment	Hot Strip Mill Water	Central Water Treatment	Lined Onsite Landfill	Scarfing Air
9	Electric Arc Furnace Air	Electric Arc Furnace Air	Lined Onsite Landfill	Coke Quenching Air	Cold Forming Water
10	Open Hearth Furnace Air	Lined Onsite Landfill	Electric Arc Air	Electric Arc Air	Coke Oven Door Air

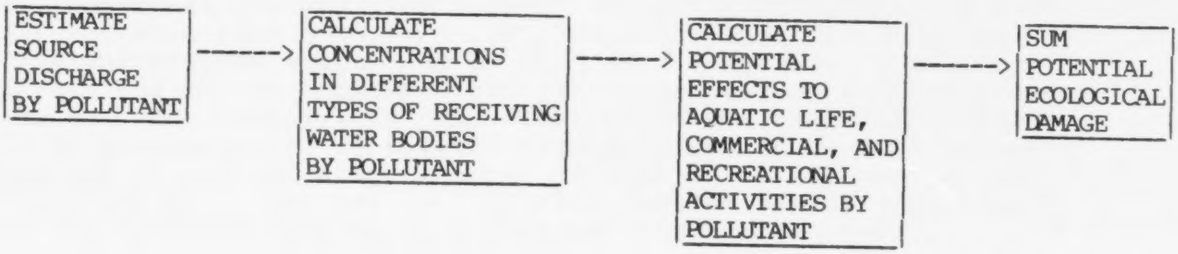
Figure 1. Top ten controls for health cost-effectiveness.

To explain what these findings mean, let's assume that the ten controls are the only controls we are concerned about. First, the results indicate that air controls on coke charging and coke by-product recovery operations and electric arc furnace emissions will provide significant reductions in potential health effects for the cost regardless of exposure conditions. Second, in many cases, the same is true for lined landfills, coke quenching emissions, and hot strip mill wastewater treatment, while treatment of hot forming wastewater is among the top ten most cost-effective controls in only two of the environments. This is probably because these environments include smaller receiving water bodies, increasing the potential health effects associated with the use of surface water as drinking water. Finally, several air controls appear to be much more cost-effective in Environment #5 than in other environments. This is most likely because higher a population is exposed to higher levels of air pollution risk, which takes into account the relatively higher levels of background pollution.

USING THE RESULTS

The approach discussed above, and some of the tools it is based upon, can be used to set priorities in the regulatory development process by (1) concentrating resources on sources of pollution that appear to be the most serious sources of risk; and by (2) attempting to develop control strategies that will provide the most protection for the cost regardless of exposure conditions. This approach can also be used at the state level to introduce consideration of cost, risk and intermedia transfer into control decisions made to meet emission limits and standards.

Given emission estimates, the methodology can be used to point to the largest sources of risk among unregulated point and nonpoint sources. For example, in the case of sources of water pollution, the ecological effects scoring systems can be used to screen for the worst problems in the following way:


ESTIMATE SOURCE DISCHARGE BY POLLUTANT
------>
CALCULATE CONCENTRATIONS IN DIFFERENT TYPES OF RECEIVING WATER BODIES BY POLLUTANT
------>
CALCULATE POTENTIAL EFFECTS TO AQUATIC LIFE, COMMERCIAL, AND RECREATIONAL ACTIVITIES BY POLLUTANT
------>
SUM POTENTIAL ECOLOGICAL DAMAGE

Once a source is selected for regulation, simple source models can provide a cost/risk ranking of control options, taking into account intermedia cost and risk implications. For example, these two air control options can be compared.

$$\boxed{\begin{array}{l}\text{DRY AIR}\\ \text{POLLUTION}\\ \text{CONTROL}\end{array}} + \boxed{\begin{array}{l}\text{WASTE}\\ \text{DISPOSAL}\\ \text{OF AIR}\\ \text{CONTROL DUST}\end{array}} = \frac{\text{COST A}}{\text{EFFECTIVENESS A}}$$

$$\boxed{\begin{array}{l}\text{WET AIR}\\ \text{POLLUTION}\\ \text{CONTROL}\end{array}} + \boxed{\begin{array}{l}\text{RESIDUAL}\\ \text{WATER}\\ \text{TREATMENT}\end{array}} + \boxed{\begin{array}{l}\text{RESIDUAL}\\ \text{SLUDGE}\\ \text{DISPOSAL}\end{array}} = \frac{\text{COST B}}{\text{EFFECTIVENESS B}}$$

In the case of state regulators and plant managers, the approach can be used to set priorities and evaluate control options to meet State Implementation Plan (SIP) requirements and water quality standards.

For example, suppose a hypothetical Air Quality Control Region includes one industrial source comprised of several process stacks that emit particulate matter. To meet the National Ambient Air Quality Standard for particulates, total emissions from the source may not exceed a level that is above the standard, when dispersed in the ambient air. A traditional way of determining the best way to meet the standard is to estimate the amount of particulates that could be removed from each stack and the costs involved and then select those that provide the required reduction in emissions for the least cost.

In contrast, an integrated approach ranks controls according to cost per unit of risk reduced. Risk reduction is calculated by taking into account the potential health or environmental effects that are prevented per ton of particulates removed from various process emissions. The ranking may look very different from rankings assembled on a cost per ton basis because risk reduction is attributable to the prevention of several health or environmental effects from several constituents associated with particulates from a source. It recognizes that particulates from one process source may be much more dangerous to public health and the environment than particulates from another process source. For example, if hexavalent chromium, generally thought to be carcinogenic, is emitted from only one of several process sources of particulates, control of that stack may be very cost-effective on a cost per unit of risk reduced basis, regardless of its relative ranking on a cost-per-ton removed basis.

In ranking controls based on cost per unit of risk reduced, an integrated approach also takes into account the possibility that intermedia transfer of pollutants may increase risk or not reduce it as much as expected. For example, a wet air pollution control might transfer chromium into a water environment where it does not pose as great a threat to human health, but may adversely effect aquatic life. Likewise, sludges from wastewater treatment may contain cyanide which, depending on disposal method, may pose a threat to both human and aquatic life. These kinds of trade offs can be made explicit by applying an integrated approach to various control decisions.

IMPROVEMENTS AND OTHER APPLICATIONS OF THE APPROACH

Since the iron and steel pilot study, IEMD has tested several indices for assessing the impacts of water pollution control on fish and aquatic vegetation. In a study of foundries currently underway, an index of water ecological integrity has been included in the computer model. Thus, the extent to which changes in the aquatic ecosystem might occur as a result of wastewater discharges is assessed, as well as the direct and indirect economic effects associated with reductions in commercial fishing and recreational activities. This is done by relating dose response information to the surface water concentrations that result from various levels of water pollution control and assessing potential reductions in the number of plankton, nekton and sessile organisms.

IEMD has continued to develop its capabilities so that integrated analysis may be performed for different industries and broader policy issues. The result has been the ability to conduct more extensive sensitivity analysis much faster, on its own computers. More important, it enables IEMD and others to share integrated perspectives with program regulators early in the regulatory development process, rather than after regulatory decisions have been made and there is little opportunity to move toward more cost-effective solutions.

There will always be uncertainty attached to numerical estimates and assumptions contained in integrated technical models but modern computer models provide analysts with a way to test various assumptions and determine which have the greatest effect on policy alternatives. And, of course, as more and more research is done on the health and ecological effects associated with environmental pollution, and better exposure models are developed, the methodology can be modified easily to reflect the current state of the art.

CONCLUSION AND NEXT STEPS

IEMD's iron and steel pilot study examined the relative cost-effectiveness of controls, taking into account the consequences of intermedia shifts in pollutants arising from control equipment or natural processes. Further, the study demonstrated the extent to which cost-effective strategies for control of iron and steel facilities vary with exposure conditions.

In assessing the utility of this type of analysis, IEMD concluded that the industry methodology is best applied to industrial sectors that are in the process of making control decisions. In this way, it can be used to point to the pollution sources within a complex industry that current knowledge suggests, are the most dangerous to public health or the environment and to determine the most cost-effective means of controlling them _before_ control requirements are put in place.

Beyond such single-industry strategies, both the general approach and individual components of the approach that have been developed may be used to assess the multi-media impacts and relative risk implications of a number of regulatory policy issues. These range from priority setting exercises to multi-media evaluation of new kinds of pollution control and reduction technologies to dealing with the control of several different source types located in particular geographic areas.

AIR POLLUTION IMPACTS OF QUENCHING BLAST FURNACE SLAG WITH CONTAMINATED WATER

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ABSTRACT

One inexpensive method of blast furnace wastewater disposal that results in no release of residual water pollutants is the use of blowdown water to quench hot blast furnace slag. The resulting evaporation of the water is accomplished by using energy that would normally be lost to the plant, and the results are zero discharge of wastewater from the blast furnace. A concern is that previous EPA tests of coke quenching with water containing high levels of dissolved solids indicated that this practice tended to generate high levels of fine particulate air emissions, and it is conceivable that other contaminants in the water could vaporize to create undesirable air pollutants.

Under the first phase of this project, PEDCo conducted a literature survey, developed specific goals to be reached, and designed an overall test program. The second phase, which was completed in the fall of '82, involved conducting actual tests under simulated conditions. Blast furnace slag was quenched with blast furnace blowdown water in a specially designed enclosed container. The container was continuously heated to maintain quench temperatures near those encountered in the field. Further tests were conducted in February and April '84 using different contaminated water.

In the third phase, a series of six test runs was conducted at two different slag temperatures (1100° and 1500°F). The results of this laboratory-scale assessment of simulated blast furnace slag quenching with contaminated water indicated that particulate emissions increase at a more pronounced rate with high slag temperatures and higher total dissolved solids (TDS) content of the quench water. Although minor quantities of organic

pollutants evolved during quenching, the data showed no relationship between these pollutants and slag temperatures, slag characteristics, or water quality. Also, no correlation was found between quench water quality or slag temperature and emissions of sulfur dioxide, and fluoride.

INTRODUCTION

Blast furnace blowdown water can be disposed of in several ways. One option is to use this water for slag quenching. Because this water evaporates during the slag quenching, the discharge of this contaminated liquid stream is greatly reduced or eliminated. Effluent limitation guidelines and standards proposed by the U.S. Environmental Protection Agency designate this disposal method as Alternative I of the Best Available Technology for handling blast furnace wastewater. A report describing the results of an environmental assessment project to evaluate the air emissions arising from quenching blast furnace slag with the blowdown from a blast furnace scrubber wastewater recirculation system was presented at Iron & Steel Pollution Abatement technolgoy symposium in October 1983 at Chicago.

Previous studies have shown that quenching hot coke with coke plant wastewater can give rise to significant emissions. Two major differences, however, exist between slag quenching and coke quenching: 1) slag quenching does not evaporate nearly as much water as coke quenching (15 to 30 gal/ton of slag versus 150 gal/ton of coke), and 2) the contaminant level of blast furnace blowdown water is generally lower than that of coke process waters.

In the first phase of this study (1), an evaluation was made of water consumption in various slag processing methods. The three processing methods practiced in the United States involve the use of hard slag pits, expanded slag, and granulated slag. Because about 90 percent of total slag production entails the use of the hard slag pit method (in which water is sprayed on slag after it has solidified), the previous study focused on this method.(2)

The testing approach selected in the previous study involved simulated slag quenching in a laboratory. This approach, which entailed the construction of a furnace that would indirectly reheat fresh slag, offered the following advantages. First, all work could be done under controlled conditions, and accurate measurements could be made of slag, water, and emissions. Second, duplicate testing under a range of conditions could be made at much lower cost than in field testing. The disadvantages were that it was not possible to collect emissions from the quenching of fresh molten slag, no runoff water could be generated because of the inherent design of this approach, and the water evaporation occurred in a semisealed container, which probably excluded potential reactions with air.

This study revealed a direct relationship between the content of total dissolved solids (TDS) in the quench water and the resultant level of particulate emissions. A direct relationship was also found between the slag temperature and particulate emission rates. Based on the limited data obtained in this work, no correlation could be drawn between slag temperature or level of specific contaminants in the quench water and the resulting air emissions of that contaminant. The purpose of the later assignment discussed here was to expand the data base by measuring atmospheric emissions during blast furnace slag quenching with very clean water and with contaminated water.

Slag was poured into the slag pots at the blast furnace and transported to the experimental furnace. Blowdown water was obtained from another blast furnace with a moderately tight recycle system and transported to the laboratory in 5-gallon jars. Coke plant wastewater obtained from a coke plant was diluted to ≅2500 mg/liter of total dissolved solids (TDS) and used for quenching. ASTM Type I water with low TDS and no organics was used as a baseline for comparison. A series of six test runs was conducted at two different ranges of slag temperature. These tests provided a qualitative estimate of emissions under different slag temperatures and the effect of the use of different types of water on these emissions.

EQUIPMENT DESIGN

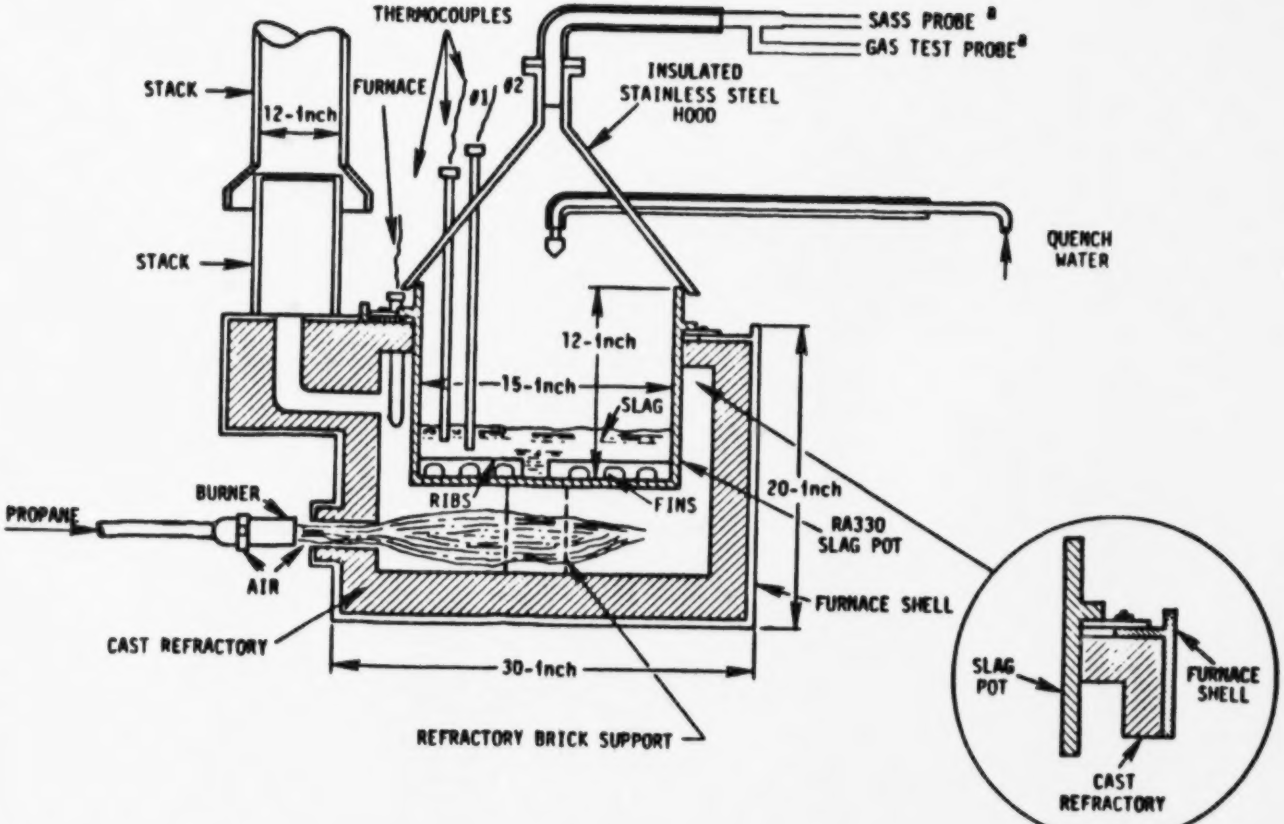
Figure 1 shows the general arrangement of the experimental setup. The slag pots are designed to withstand the severe thermal stress of being continuously heated for 4 to 6 hours while the slag was simultaneously quenched inside the pot. They also had to withstand the high temperatures of the molten slag.

Figure 2 presents two photographic views of the actual setup during the test run. The slag pots were made of RA-330, a high-temperature stainless steel. The bottom of the pot was reinforced with pie-slice ribs, which also aided in heat transfer to the slag. Additional fins were provided for better heat transfer. The furnace was custom-designed. The emission capture hood was made of 304 stainless steel. Two special probes were used and attached to the stainless steel connecting pipe from the emission collection hood. One probe was connected to the SASS train, and the other was used to collect other gases. The probe was glass-lined and had the necessary electrical heating arrangement. A special glass filter assembly designed to hold a 6 in.-diameter Whatman filter paper was used. The inlet pipe for the blowdown water was a stainless steel pipe with a cooling-water jacket. This arrangement was selected to ensure that the blowdown water did not evaporate before hitting the hot slag surface.

TEST DESIGN

The main objective of the test series was to evaporate water contaminated at various levels on the hot blast furnace slag and correlate air and water discharges and slag characteristics as a function of quench water quality and slag temperature.

The baseline water was ASTM Type I pure water, free of any organics and with low TDS content. The baseline pure water sample was distilled in PEI's laboratories. The blast furnace blowdown water also was obtained in 5-gallon glass jars from a blast furnace shop. The measured TDS content was 1290 mg/liter. The blast furnace wastewater treatment system uses moderately



THERMOCOUPLES
SASS PROBE [a]
GAS TEST PROBE[a]
STACK
12-inch
FURNACE
#1
#2
INSULATED STAINLESS STEEL HOOD
STACK
QUENCH WATER
12-inch
15-inch
SLAG
BURNER
PROPANE
RIBS
FINS
20-inch
RA330 SLAG POT
AIR
FURNACE SHELL
CAST REFRACTORY
30-inch
REFRACTORY BRICK SUPPORT
SLAG POT
FURNACE SHELL
CAST REFRACTORY

[a] The Probe not in use will be sealed with a glass socket.

Figure 1. General arrangement of the experimental setup (not to scale).

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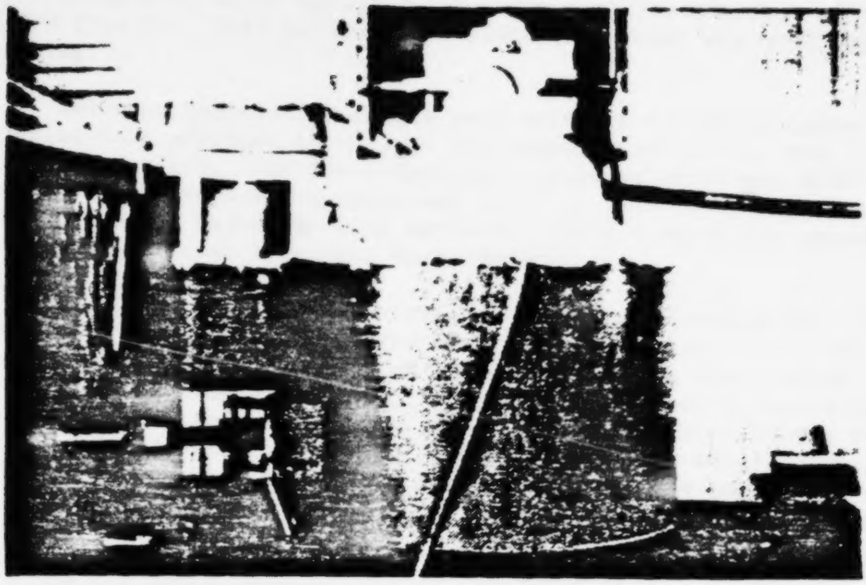

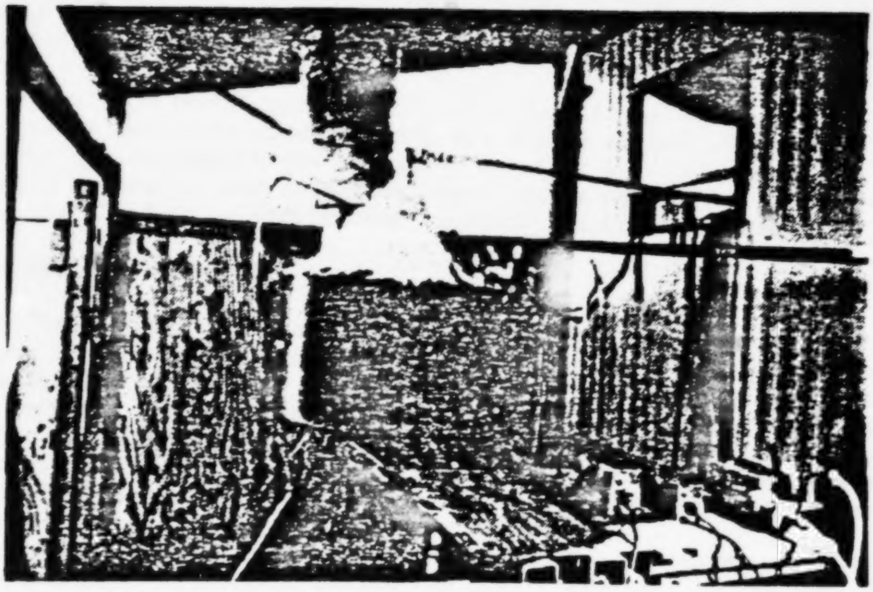

Figure 2. Two views of the actual experimental setup of slag pot and furnace.

tight recycle. The untreated coke plant wastewater was obtained from another coke plant in 5-gallon jars. The raw water was analyzed for TDS content and then dilutes to ≅2500 mg/liter TDS content by the addition of pure water (ASTM Type I). This diluted coke-plant wastewater was used for quenching the BF slag.

Two slag temperature ranges were selected for these tests. The thermocouples were arranged to measure the temperature 1/2 in. and 1-1/2 in. below the slag surface. The low-temperature range selected was 1000° to 1100°F, and the high-temperature range was 1500° to 1600°F, as measured by the thermocouple 1/2 in. below the slag surface. Table 1 shows the sequence of sampling runs, quench water type, and slag temperature.

The slag samples were obtained from a blast furnace shop in batches of three. After the pots were thoroughly cleaned, they were taken to the blast furnace casthouse, where molten blast furnace slag was removed from the slag runner with a slag spoon during a cast. It was poured into each pot one spoonful at a time and allowed to solidify. This process was repeated until a height of ≅2-1/2 to 3 in. was reached (≅25 lb of slag). The pots were then allowed to air-cool before being transported to the laboratory. The pots were kept covered to avoid any contact with moisture until the time of the test.

In the selected test approach the slag was heated in the pot to the predetermined temperature and maintained at that temperature while the slag surface was being quenched. The emissions and steam generated during the quench were collected. This prolonged quenching period at a desired temperature allowed collection of a large volume of emissions. The extended sampling period was required because of the expected low concentrations of trace metals and organics.

For each test, approximately 15 liters (4 gallons) of the specified type of quench water was used. During the entire period of each test, the water in the jar was kept under agitation by using a 1/3-hp mixer with a Teflon paddle to ensure that no solids would settle out in the jar. A spray nozzle was installed to provide uniform application of the quench water to the slag.

AIR SAMPLING APPROACH

Steam and air contaminants generated from slag quenching with the three types of quench water were sampled and analyzed for various pollutant species. The results of the ASTM Type I water tests served as a baseline against which to evaluate emissions from the contaminated waters. For each type of quench water two tests were conducted to determine the composition of the emissions generated at the different slag temperature. Table 2 shows the sampling methods and analytical procedures followed during the test series.

A modified Source Assessment Sampling System (SASS) train was chosen as the principal collection device for three reasons: 1) the sample rate can be varied up to approximately 114 liters/min (4.0 ft^3/min), 2) a larger sample volume can be collected, and 3) the sampling train is designed to maintain a high temperature of 205°C (400°F). The SASS train was operated without cyclones. The only modifications to the SASS train were a glass-lined probe

TABLE 1. AIR EMISSION SAMPLING SCHEME

Test run No.	Quench water type	Slag temperature, °C (°F)
1	ASTM Type I	593 (1100)
2	ASTM Type I	816 (1500)
3	Blast furnace blowdown (TDS ∿1250 mg/liter)	593 (1100)
4	Blast furnace blowdown (TDS ∿1250 mg/liter)	816 (1500)
5	Coke-plant wastewater[a] (TDS ∿2500 mg/liter)	593 (1100)
6	Coke-plant wastewater[a] (TDS ∿2500 mg/liter)	816 (1500)

[a] The coke-plant wastewater TDS will be adjusted to ≈2500 mg/liter by adding ASTM Type I water.

NOTE: After the particulate and organic samples were collected by SASS train, other sampling trains were used to collect F^-, Cl^-, CN^-, and NH_3.

TABLE 2. SAMPLING METHODS AND ANALYTICAL PROCEDURES FOR AIR SAMPLES

Species	Sampling method	Analytical procedure
H_2O	SASS	Gravimetric
SO_2	SASS	EPA Method 6
F^-, Cl^-	EPA Method 13B	EPA Method 13B
CN^-	EPA Method 13B	808[a]
NH_3	Impinger train	801[a]
Particulates	SASS	EPA Method 5 (front-half only)
Volatile organics (C_1 to C_7)	Grab samples	GC/FID
Organics	SASS	Modified Level 1[b]
Metals	SASS	ICP

[a] Sampling method numbers taken from "Methods of Air Sampling Analysis," 2d ed., American Public Health Association, 1977.

[b] IERL-RTP Procedure Manual: Level 1 Environmental Assessment (Second Edition). EPA-600/7-78-201, October 1978.

and glass filter holder, which significantly improved sample quality, especially for trace element determinations. The SASS train was operated for approximately 4 to 6 hours per run.

TEST RESULTS

The evaluation of the test data in terms of water quality, slag temperature during quenching, and slag characteristics is presented under the following subcategories: particulate emissions, sulfur dioxide, hydrogen cyanide, ammonia, fluorides, chlorides, hydrocarbons C_1 to C_7 and C_7 to C_{16}, organic emissions, and metals. All emissions except C_1 to C_7 are expressed in terms of milligrams or micrograms per liter of water evaporated on the slag surface during quenching. In all cases, the water evaporated is the same as the water applied. The water recovered was always less than the water applied.

Particulate Emissions

The level of particulate emissions was related to two conditions: the total dissolved solids (TDS) content of the quench water and the temperature of the slag. Emissions were as follows.

Type of quench water	TDS content, mg/liter	Average slag temperature, °F	Particulates, mg/liter of water evaporated
ASTM Type I	29	1112	80.3
ASTM Type I	29	1493	86.7
BF Blowdown	1305	1089	277.2
BF Blowdown	1305	1498	271.5
Coke plant wastewater	2637	1093	157.0
Coke palnt wastewater	2637	1490	192.8

Table 3 shows a composite of the current data and the data obtained during fall of 1982 (second phase), when similar simulated laboratory-scale tests were conducted using well water and BF blowdown water as quenching medium. Table 3 shows that for a comparable TDS content of coke plant wastewater (2637 mg/liter) the particulate emissions are approximately 50 percent lower than for an equivalent BF blowdown water (TDS, 2491 mg/liter) at high-temperature slag quench. This result is expected because the species of pollutants present in the two types of water are different, and in coke plant water the pollutants break down at high temperatures.

Figure 3 shows the relationship between particulate emissions, the TDS of quench water, and slag temperature. The high-temperature and low-temperature estimated regression lines (excluding coke plant wastewater data) and 95 percent confidence limits (dotted lines) for both high- and low-temperature quench are indicated. The high-temperature data correlation coefficient is 0.9669 and the spread for the 95 percent confidence limit is narrow compared with the low-temperature data, which has a lower correlation coefficient of 0.603. The noise level in the data (due to many variables affecting quenching)

TABLE 3. PARTICULATE EMISSIONS FROM QUENCHING OF BLAST FURNACE SLAG WITH CONTAMINATED WATER

Type of quench water	TDS content, mg/liter	Particulate emissions, mg/liter of quench water applied and evaporated: Low-temperature quench (≅1100°F)	Particulate emissions, mg/liter of quench water applied and evaporated: High-temperature quench (≅1500°F)
ASTM Type I	29	80.3	86.7
Well water	450	23.1	27.8
	450	25.1	75.2
	450	55.9	
BF blowdown (moderate recirculation)	1305	277.2	271.5
BF blowdown (high recirculation)	2491	133.7	377.8
	2491	151.3	392.6
	2491	183.8	415.3
Coke plant waste water (diluted with ASTM Type I)	2637	157.0	192.8

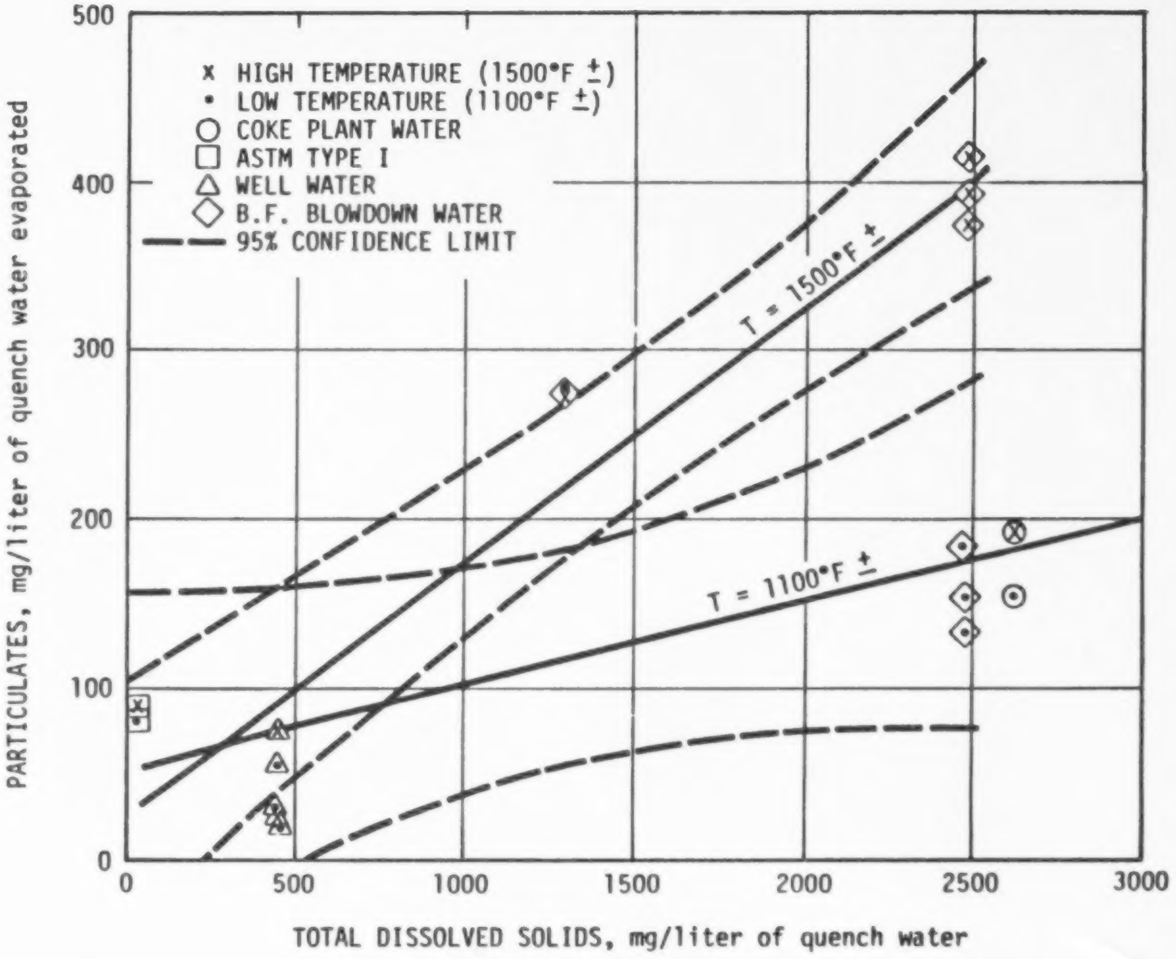

Figure 3. Particulate emissions vs. total dissolved solids in quench water.

is high at the lower temperature range as expected because the effect of other variables overhelms the quench water effect.

It is apparent that a high amount of TDS in the quench water and a high temperature during the quench will yield high particulate emissions.

Based on this and the previous experimental data, an emission factor for slag quenching with BF blowdown water (TDS ≅2500 mg/liter) at two slag temperature ranges was calculated for hard slag quenching.

Low-temperature slag quench: (14.5 gal of quench water evaporated per ton of hot metal and a slag volume of 670 lb/ton of hot metal)	0.021 lb/ton of hot metal
High-temperature slag quench: (12.47 gal of quench water evaporated per ton of hot metal and a slag volume of 670 lb/ton of hot metal)	0.042 lb/ton of hot metal

Sulfur Dioxide, HCN, Ammonia, Fluorides, and Chlorides

Results of the air samples collected are presented below. The units in the last column for each pollutant are expressed as mg/liter of quench water applied.

Sulfur Dioxide (SO_2)

Sulfur dioxide data were collected during all six SASS train runs in two groups. The resulting data are as follows:

(First Group)

Type of water	Slag temperature, °F	Slag sulfur content, %	Sulfur in water sample, mg/liter	SO_2 emissions, mg/liter
ASTM Type I	1105	1.37	0.2	165.2
ASTM Type I	1443	1.37	0.2	334.3
BF blowdown	1105	1.37	81.0	254.8
BF blowdown	1531	1.26	81.0	75.8
Coke plant wastewater	1104	1.26	800.0	268.5
Coke plant wastewater	1458	1.26	800.0	1312.0
(Second Group)				
ASTM Type I	1112	1.58	<0.03	377.5
ASTM Type I	1493	1.58	<0.03	408.8
BF blowdown	1089	1.58	40	345.4
BF blowdown	1498	1.23	40	341.4
Coke plant wastewater	1093	1.23	680	488.5
Coke plant wastewater	1490	1.23	680	1201

The SO_2 content of the emissions does not show any definite relationship to water quality, slag sulfur content, or quench temperature.

Hydrogen Cyanide (HCN)

The HCN test data are as follows:

Type of water	Slag temperature, °F	Total cyanides in water sample, mg/liter	Total cyanide, mg/liter
ASTM Type I water	1107	<0.02	<0.016
ASTM Type I water	1472	<0.02	<0.018
BF blowdown water	1093	0.09	0.019
BF blowdown water	1506	0.09	<0.018
Coke plant wastewater	1105	2.26	4.700
Coke plant wastewater	1500	2.26	4.100

The total cyanide data indicate cyanide dissociation at both low- and high-temperature slag quench for BF blowdown water.

Ammonia

The ammonia test data are as follows:

Type of water	Slag temperature, °F	Ammonia (N) in water, mg/liter	Ammonia, mg/liter
ASTM Type I water	1076	1.3	<0.5
ASTM Type I water	1471	1.3	<0.2
BF blowdown water	1122	20.1	21.2
BF blowdown water	1468	20.1	12.2
Coke plant wastewater	1128	683	530.2
Coke plant wastewater	1489	683	142.2

The ammonia appears to dissociate at higher temperatures. The ammonia emissions tended to be higher when the quench water contained higher ammonia concentrations.

Fluoride

The fluoride test data are as follows:

Type of water	Slag temperature, °F	Fluorides in water, mg/liter	Fluorides, mg/liter
ASTM Type I water	1107	0.04	59.7
ASTM Type I water	1472	0.04	103.2
BF blowdown water	1093	8.28	37.3
BF blowdown water	1506	8.28	60.8
Coke plant wastewater	1105	5.13	49.6
Coke plant wastewater	1500	5.13	112.5

Quenching of higher temperature slag appears to increase total emissions regardless of water quality and the total fluoride content. Most of the metallic fluorides (e.e., ZnF and KF) are highly soluble in water. Because there is no run-off water in these tests, the fluorides content in emissions in these tests may be higher than would be the case during actual operations.

Chlorides

The chloride test data are as follows:

Type of water	Slag temperature, °F	Chlorides in water, mg/liter	Chlorides, mg/liter
ASTM Type I water	1107	<0.3	5.8
ASTM Type I water	1472	<0.3	6.4
BF blowdown water	1093	318.0	124.2
BF blowdown water	1506	318.0	203.7
Coke plant wastewater	1105	1160.0	792.4
Coke plant wastewater	1500	1160.0	659.2

The chloride emissions are higher at high-temperature slag quench (except for coke plant water quench). The chloride emissions are higher if the quench water contains a higher chloride concentration.

HYDROCARBONS AND ORGANIC CARBON

Grab samples were taken for each test run and analyzed for hydrocarbons C_1 through C_7. The values of C_1 through C_7 (total) varied from 4.2 ppm to 36.0 ppm. The evolution of C_1 through C_7 did not show any relationship to quench water or slag temperature.

Total organic carbon (C_7 - C_{16}) in air samples per liter of water applied did not show any relationship to quench water type or slag temperature in ASTM Type I and BF blowdown water. In coke plant water, however, the organics appear to break down at higher quench temperature.

In the analysis of the total organic carbon (C_7 - C_{16}), a 50/50 solution of methylene chloride and acetone was used for recovery of front-half rinses. It appears that use of acetone for this extraction is likely to generate contamination; hence the results of total organic carbon (C_7 - C_{16}) may be biased on the higher side. Because the overall generation of total organic carbon is at low levels, any errors due to contaminations arising out of the use of acetone may not be significant.

METALS

The data for 29 metals were analyzed by inductively coupled plasma optical spectrometry (ICAP) for emissions under the different test conditions. In general, the tendency was toward higher emissions of aluminum, calcium, potassium, sodium, silicon, and boron with higher slag temperatures, which is in line with particulate emissions.

ORGANICS

Both ASTM Type I water and BF blowdown water did not contain any of the priority pollutants. Selected runs, however, showed the presence of the following in the air emissions collected.

	ASTM Type I water	BF blowdown water
Phenol	2 out of 2 samples	1 out of 2 samples
Benzoic acid	2 out of 2 samples	0 out of 2 samples
Fluroanthene	2 out of 2 samples	1 out of 2 samples
Naphthalene	2 out of 2 samples	1 out of 2 samples
Bis(2-ethylhexyl) phthalate	2 out of 2 samples	2 out of 2 samples
Benzyl butyl phthalate	1 out of 2 samples	2 out of 2 samples
Di-N-butyl phthalate	2 out of 2 samples	1 out of 2 samples
Di-N-octyl phthalate	2 out of 2 samples	2 out of 2 samples
Diethyl phthalate	1 out of 2 samples	2 out of 2 samples
Dimethyl phthalate	1 out of 2 samples	0 out of 2 samples
Pyrene	2 out of 2 samples	1 out of 2 samples
4-chloroaniline	2 out of 2 samples	1 out of 2 samples
Dibenzofuran	0 out of 2 samples	1 out of 2 samples
2-methyl naphthalene	1 out of 2 samples	1 out of 2 samples

CONCLUSIONS

The laboratory-scale assessment of simulated blast furnace slag quenching with pure and contaminated waters produced the following major findings and conclusions:

1. Particulate emissions, as measured by the front half of the modified SASS train during blast furnace slag quenching, increase with increasing slag temperature. The higher the TDS in the quench water, the more pronounced the increase becomes. The estimated regression line equations for low and high slag temperature quench are as follows:

   $y = 53.5 + 0.0495\,x$ (for low temperature ≅ 1100°F)
   $y = 30.38 + 0.14779\,x$ (for high temperature ≅ 1500°F)

   where, x is the TDS content of the quench water and y is the particulate emissions (mg/liter of quench water evaporated).

2. Based on this laboratory-scale simulation, the emissions generated during slag quenching at high temperatures with coke-plant wastewater with a comparable TDS content of that of BF blowdown water are considerably less than those generated when using BF blowdown water. The pollutants present in the coke-plant water appear to break down at high-temperature slag quenching and result in less particulate emissions.

3. Emissions of metals increase with high-temperature slag quenching.

4. No specific relationship was found between organic pollutants and the use of ASTM Type I water or BF blowdown water and slag temperature during quenching. Significant amounts of priority pollutants were dissociated in the coke-plant wastewater at both low- and high-temperature slag quenching when all the applied water was evaporated.

5. No correlation was found between quench water quality, slag temperature, or slag sulfur content and emissions of SO_2.

6. Chloride emissions are higher during high-temperature slag quenching. The emissions are higher when the quench water contains higher chloride concentration.

7. Cyanides appear to dissociate at both low- and high-temperature slag quenching with BF blowdown water.

8. Ammonia appears to break down at higher-temperature quenching. The ammonia emissions are higher when the quench water contains higher ammonia concentrations.

9. Fluoride emissions increase at higher-temperature slag quenching, and they bear no relationship to the quench water quality.

RECOMMENDATIONS

It is recommended that the test data and findings of this project be verified by tests conducted at a suitable plant site that practices hard slag quenching with mill service water, blast furnace blowdown water, and if possible, coke-plant wastewater.

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Appendix A

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